ENERGY EFFICIENT BUILDING RETROFIT STRATEGIES FOR TROPICAL CLIMATES: A CASE STUDY OF A SALVADORAN UNIVERSITY

By

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ABSTRACT

ENERGY EFFICIENT BUILDING RETROFIT STRATEGIES FOR TROPICAL CLIMATES: A CASE STUDY OF A SALVADORAN UNIVERSITY

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This project presents multiple retrofit solutions to reduce energy consumption in the buildings of the *Universidad Don Bosco* (UDB) campus in Soyapango, El Salvador. Energy efficiency investments are a financially viable way to decrease energy use, reduce greenhouse gases, and earn positive monetary returns. This project identifies the critical energy losses in three energy intensive UDB campus buildings by means of energy audit practices and detailed analyses. Specific energy saving retrofits were developed using the building simulation software eQuest. Multiple retrofit options are presented to provide university administrators with flexibility in selecting the most appropriate solutions based on their budgetary constraints and energy efficiency goals.

From nineteen UDB campus buildings, the three buildings selected for in depth study were the Mechanical Workshop, the Cisco Building, and the Studio Building (known as *El Taller Mecánico*, *Edificio Cinco*, and *Edificio Dos* at UDB). The majority of energy wasted in these buildings is due to four causes: (1) excessive heat gain from the corrugated metal roofs, (2) air infiltration into conditioned spaces, (3) inefficient cooling equipment, and (4) unnecessary lighting. Specifically, the three most favorable retrofits investigated were: (1) reducing infiltration rates in the Studio Building, (2) implementation of a cool roof for the Mechanical Workshop, and (3) upgrading to SEER

13 cooling equipment in the Mechanical Workshop. These retrofits are expected to save 4.0 MWh/year (1), 5.5 MWh/year (2), and 28.9 MWh/year (3) respectively and the discounted payback periods are forecasted at 7.1 years (1), 7.7 years (2), and 7.0 years (3), respectively.

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I could not have completed this project without the support and guidance of my mentor, Richard Engel of the Schatz Energy Research Center. Getting my feet on the ground in El Salvador would have been significantly more difficult had Richard not accompanied me during my first week within the country. I am thankful to have been able to work alongside his professional demeanor, which taught me how to carry myself in a diplomatic way while working internationally. Richard also provided me with ideas, resources, and critical feedback that were fundamental to this project's completion.

In addition, Arne Jacobson deserves mention for his attention to detail in revising my project and for his excellent instruction during my Master's coursework. My academic advisor Charles Chamberlin and HSU graduate engineering students Tom Quetchenbach, Chelsea McNeal, Teresa Garrison, and Robert Hosbach have been indispensible as well, all of whom provided helpful comments and feedback on my project.

I would also like to take this opportunity to thank my mother, as she has consistently supported me and encouraged me to pursue my interests. Without her love and inspiration, I don't think I would ever have attempted a Master's degree in engineering in the first place. And finally, I would like to thank my sweetheart Liz, whose support and playful spirit kept my heart lifted even during the most challenging times of my work.

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LIST OF ABBREVIATIONS

AEA	Partnership in Energy and Environment (English translation)
AC	Air-conditioning
ACH	Air Changes per Hour
ASHRAE	American Society of Heating, Refrigeration, and Air-conditioning Engineers
BEU	Building Energy Use (MWh/year)
BEUI	Building Energy Use Intensity (kWh/ft^2/year)
CDD	Cooling Degree Day
cfm	Cubic feet per minute
cfm$_{50}$	Cubic feet per minute at 50 Pascals
CIER	Renewable Energy Research Center (English translation)
COP	Coefficient of Performance
DOE	U.S. Department of Energy
ECM	Energy Conservation Measure
ELA	Estimated Leakage Area
EPA	Environmental Protection Agency
eQuest	Quick Energy Simulation Tool
FSEC	Florida Solar Energy Center
GHG	Greenhouse Gas
GWP	Global Warming Potential (W/m^2)
HEIF	Humboldt Energy Independence Fund
HSU	Humboldt State University
HVAC	Heating Ventilation and Air-Conditioning
IES	Illuminating Engineering Society
IRR	Internal Rate of Return
LBL	Lawrence Berkeley (National) Laboratory
MBtu	Million (10^6) British Thermal Units
NPV	Net Present Value
OLADE	Latin American Energy Organization (English translation)
PV	Photovoltaic
R-value	The thermal resistance of a material (°F·ft^2·h/Btu)
SEER	Seasonal Energy Efficiency Ratio (Btu/W·hr)
SIGET	The Salvadoran Organization for Oversight of Electricity Networks (English translation)
tCO$_2$e	Metric tons of carbon dioxide equivalent
UDB	Universidad Don Bosco
UNDP	United Nations Development Program
USD	United States Dollars
W	Watt

CHAPTER 1 INTRODUCTION

This project presents multiple retrofit solutions to reduce energy consumption in the buildings of the *Universidad Don Bosco* (UDB) campus in Soyapango, El Salvador. The critical energy losses in three energy intensive UDB campus buildings were identified by means of energy audit practices and detailed analyses. From the ranking of nineteen UDB campus buildings, the three buildings selected for in depth study were the Mechanical Workshop, Cisco Building, and Studio Building (known as *El Taller Mecánico*, *Edificio Cinco*, and *Edificio Dos* on the UDB campus). Specific energy saving retrofits for these buildings were developed using the building simulation software eQuest. Multiple retrofit options are presented in this report to provide university administrators with flexibility in selecting the most appropriate solutions based on their budgetary constraints and energy efficiency goals.

1.1 Project Need

The construction and operation of buildings consumes over a third of the world's energy production and 40% of all mined resources (Straube, 2006). It has been estimated that in developing nations, buildings account for 20-40% of total energy consumption (Perez-Lombard et al., 2007). Given that buildings comprise a large portion of global energy use, they have significant environmental impacts, which are most commonly seen in the forms of fossil fuel combustion, air pollution, production of greenhouse gases, and non-renewable natural resource consumption. According to a 2009 McKinsey feasibility analysis, improving energy efficiency in buildings is one of the most financially viable means for greenhouse gas abatement and often results in negative project costs over the long term. Additionally, investment in energy efficiency can lower energy bills, stabilize energy prices, reduce demand for fossil fuels, defer the need for new infrastructure, and help reduce air pollutants (EPA, 2008)

Government policies at state and local levels have the ability to stimulate private investment and development of renewable energy and energy efficiency technologies (Beck and Martinot 2004, and EPA 2007). In El Salvador, the most substantial of such policies is the Fiscal Incentives Law for the Promotion of Renewable Energy, which was passed in November 2007, and provides a ten-year tax exemption for renewable energy projects less than 10 MW. However, no equivalent incentive program currently exists to promote energy efficiency projects or research (Lokey, 2009). While current El Salvador president Mauricio Funes has acknowledged that deepening efforts to pursue sustainable energy are essential for addressing climate change (Washington Post, 2011), few energy efficiency projects have been realized with government aid.

There are likely two reasons for this lack of governmental support. The first is the limited amount of available capital within the country. El Salvador is generally a marginalized nation with 37.8% of the population living below the poverty line (CIA, 2011a). The second reason is that El Salvador is plagued with problems of gang crime, violence, and slow economic growth, which tend to take political priority over issues such as climate change and energy efficiency (Stephens, 2010). Despite minimal support from the state sector, El Salvador has obtained funding for several energy efficiency projects in buildings through various international development organizations such as the United Nations Development Program (UNDP), Global Environmental Facility (GEF), and Germany's GIZ International Services. The most notable of these ventures is a 4.3

million dollar UNDP project to employ energy efficiency measures in public buildings over the next three years.

1.2 Project background

In 2010, my mentor Richard Engel worked as a guest instructor at UDB under a Fulbright scholarship. Richard helped develop UDB's new master's degree program in renewable energy management, and during his half-year stay, he saw how an international collaboration between HSU and UDB could advance El Salvador's technical capacity in the fields of renewable energy and energy efficiency.

Richard proposed the idea of an inter-university collaboration before the end of his Fulbright scholarship. He viewed this collaboration as an essential step in establishing UDB as the first Salvadoran university dedicated to energy efficiency and renewable energy technology research and development. Such a partnership would also offer unique learning and research opportunities to students and faculty from HSU and UDB. In June 2010, president Rollin Richmond of HSU and president Federico Huguet of UDB signed the official framework agreement for the two universities to participate in academic exchanges. This project is a result of that agreement and its completion is intended to strengthen the relationship between the two universities so they may both continue to advance their international research interests.

1.3 Objectives

The objective of this work was to carry out a practical project that would contribute to El Salvador's nascent energy efficiency developments, as well as improve energy efficiency awareness on the UDB campus. Specifically, I performed a broad scale energy audit of the *Universidad Don Bosco* main campus. My primary methods in achieving this goal were as follows: (1) analyze past UDB energy records and make on-site measurements to identify how energy is used on the main campus, (2) identify three energy-intensive buildings with high potential to reduce energy use, and (3) conduct an in-depth study of those buildings in order to provide energy savings recommendations with accompanying economic analyses. Additionally, as part of the collaboration between HSU and UDB, I wanted the UDB campus to benefit from HSU's previous energy efficiency methodologies and lessons learned. To fulfill this objective, I observed the key differences in energy use between the two universities to see how energy efficiency efforts at HSU could potentially be applied to UDB.

1.4 Document Roadmap

In the subsequent chapters of this document I will present an overview of the relevant literature pertaining to this project (Chapter 2) followed by a description of the methodology and materials I used to complete the study (Chapter 3). In Chapter 4, I describe the process that I used to identify the three most energy intensive UDB buildings; Chapter 4 also provides a comprehensive energy intensity ranking of all buildings on UDB's main campus. Chapter 5 though Chapter 7 pinpoint the critical energy losses found in the Mechanical Workshop, Cisco Building, and Studio Building, respectively. Results from the eQuest models that address these energy losses are presented in Chapter 8; the 20-year economics of these potential building retrofits are then described in Chapter 9. Chapter 10 is a unique chapter where I compare and contrast energy use at UDB and my home university, Humboldt State University (HSU). Within Chapter 10, I also identify specific energy efficiency issues and successes that the two universities have encountered and compare them for their transferability. Last, in

Chapter 11 I present the key findings from the study and my specific energy efficiency recommendations to UDB.

CHAPTER 2 LITERATURE REVIEW

This chapter provides an overview of the relevant literature pertaining to this project. The chapter begins broadly with an overview of El Salvador's energy sector, followed by a summary of the energy efficiency efforts that have been implemented on the UDB campus to date. Last, the building design concerns, energy audit practices, and potential energy efficiency policies that are applicable to UDB are discussed.

2.1 Electric Energy Consumption in El Salvador

During 2007 – 2010, El Salvador's electric energy portfolio consisted of approximately 60 percent renewable resources including hydroelectric, geothermal, and biomass power (33%, 25%, and 2%, respectively) (SIGET, 2007-2010) (Figure 2.1). Imported bunker fuel supplied the remaining 40 percent of El Salvador's electric energy during the majority of that time, but this increased to as much as 50 percent of the country's electric energy during dry seasons when hydroelectric reservoirs were depleted (EIU, 2011). The Latin American Energy Association (abbreviated OLADE in Spanish) estimated in 2008 that El Salvador's electricity sector (geothermal, hydroelectric, bunker fuel-fired, and biomass plants) emitted 3.3 million metric tons of CO_2e into the atmosphere, which translates to roughly 592 metric tons CO_2e/GWh generated (OLADE, 2009). There are currently no statistics specific to El Salvador describing the individual carbon intensity of each energy production method.

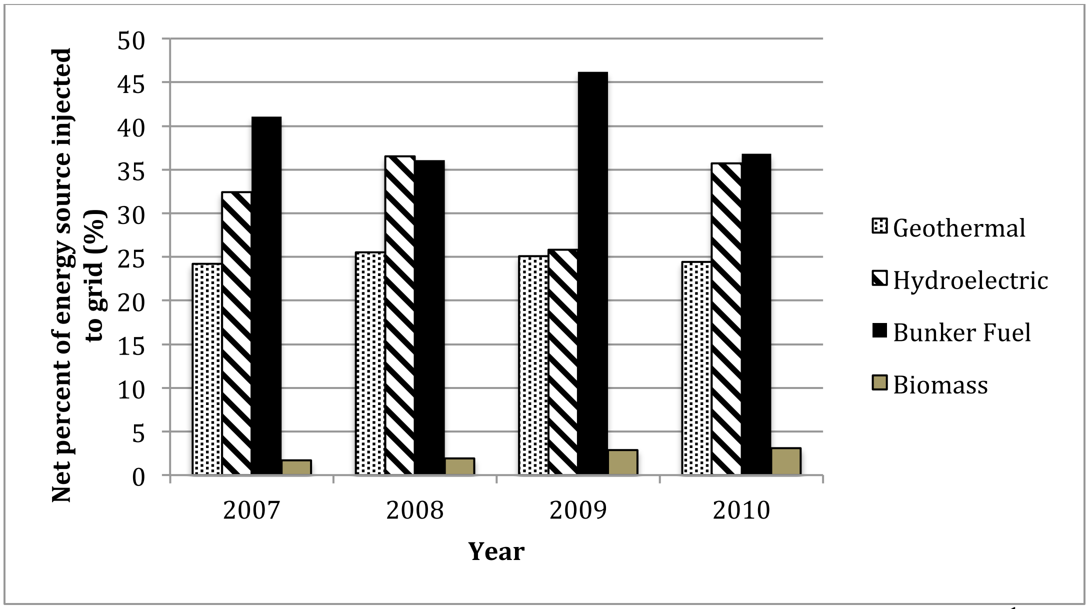


Figure 2.1: Recent trends in El Salvador's grid mix (data source: SIGET, 2007-2010)[1]

El Salvador has a relatively small national grid system, as it is located entirely within the country's borders that encompass an approximate area of 8,100 square miles. The Salvadoran Governmental Agency for Electricity and Telecommunications (abbreviated SIGET in Spanish) indicates that El Salvador exported roughly 1 percent and imported roughly 2 percent of their grid power to/from neighboring Central American countries during 2007 to 2010 (SIGET, 2010). Because El Salvador imports and exports minimal electric power, it is likely that the energy used at UDB is representative of the national grid mix.

As noted above, the carbon intensity of electricity production in El Salvador is approximately 592 tCO_2e/GWh. However, this assumption may change in future years with the planned construction of the Central American Electrical Interconnection System (abbreviated SIEPAC in Spanish) that will connect the power grids of six Central American nations. Further, El Salvador has plans to construct a 525 MW natural gas-

[1] Generated from annual reports (2007, 2008, 2009,nd 2010) published by the Salvadoran government agency SIGET. http://www.siget.gob.sv

fired power plant and a 250 MW coal-fired plant (Choto, 2010). Dates to begin construction on these projects have consistently been delayed; currently, US-based Cutuco Energy hopes to begin construction in the second half of 2014. If El Salvador commissions either one of these projects the carbon intensity of electricity production is likely to increase as the grid mix will include a greater percentage of fossil-based fuels.

From 2003 to 2009 the demand for electricity in El Salvador grew by an average of 3.9% per year (Barrera, 2011). During the same time period the average cost of electricity per kWh increased by 8.9% per year on top of the national inflation rate (SIGET, 2011). Due to the rising demand and cost of energy, it is crucial that UDB search for ways to reduce the energy consumption of the buildings on campus. El Salvador's current strategy for meeting incremental energy demand is to construct new power generation plants (mainly hydroelectric, but also the fossil-based plants mentioned above) and develop contracts with existing power producers in an attempt to guarantee a steady energy supply at reasonable prices (CEL, 2008). However, UDB has the potential to create an independent energy security plan by implementing energy efficiency measures within the university campus. Improved energy efficiency in buildings on the UDB campus would reduce dependency on outside energy sources. Less money spent on energy could also help maintain reasonable tuition costs and avoid possible budget cuts.

2.2 Energy Efficiency at UDB

UDB spends around $150,000 (USD) annually on electricity for buildings, consuming about 965 MWh. This results in emissions of roughly 571 tCO_2e each year. Electricity is the sole form of energy delivered to all classrooms and offices on the UDB campus, and propane is only consumed in significant quantities in the cafeteria kitchens.

The historic energy consumption at UDB has been poorly documented. Many buildings lack reliable sub-metered electricity data and no organized record of propane use is readily available.

To date, only two documented energy efficiency studies have been performed on UDB's main campus. These studies include an assessment of an efficient lighting technology in Engineering Building 3 (Gomez, 2011), and a study on the quality of energy received in the Technology Buildings (Machado and Monroy, 2010). No comprehensive campus-wide energy efficiency investigation has been completed, nor has the university developed a detailed energy efficiency plan for the entire campus.

The lack of research on campus energy use at UDB reflects a larger need for research and innovation in El Salvador. The Salvadoran Foundation for Economic and Social Development (abbreviated FUSADES in Spanish) states that in 2008, El Salvador ranked 127th among 131 countries in quality of research institutions (FUSADES, 2009). In 2010, the U.S. embassy made an effort to improve El Salvador's scientific research capacity by helping to establish the Center for Renewable Energy Research (CIER) on UDB's main campus. The mission statement of CIER is "to promote research and innovation of technologies related to renewable energy and energy efficiency." CIER has realized few projects hitherto because the center is in its initial stages of operation. An in-depth analysis of the energy use in buildings on the UDB campus can be seen not only as an essential step in mitigating UDB's environmental impact, but also as an important first project for CIER, an opportunity for faculty and students to collaborate on applied research, and ultimately an aid to improving El Salvador's international research ranking.

For these goals to be achieved, the mechanisms that govern building energy use in tropical climates must first be understood.

2.3 Design Concerns and Strategies for Buildings in Tropical Climates

Infiltration of outside air is a critical cause of energy loss in buildings and merits concerted efforts in energy efficiency studies (Woods and Parekh, 1992). Infiltration is defined as the uncontrolled flow of outdoor air into a building through cracks and other unintentional openings and through the regular use of exterior doors for entrance and egress (ASHRAE, 2005).[2] For air-conditioned buildings in tropical climates, air infiltration represents a major cooling load. At a rate of 0.75 air changes per hour (ACH), the infiltration in a typical residence in the tropics represents 25 to 30% of the air-conditioning load (Sheinkopf, 1989). The amount of infiltration that takes place in a building is driven by the pressure differential between the inside and outside of the building, as well as by the overall tightness of the building's envelope (floors, walls, and roof/ceiling). Therefore, it is essential to identify and seal the unnecessary openings in the building in order to reduce energy consumption.

Blower door tests can be used to measure air tightness and identify where air leakage takes place in a building envelope (Figure 2.2). In fact, virtually all knowledge of the air tightness of buildings comes from blower door technology (Sherman, 2005). A blower door test consists of depressurizing or pressurizing the building with a fan introduced through a door until a predetermined pressure difference between the outside and inside of the building is achieved.[3] The airflow required to maintain the pressure

[2] Similarly, exfiltration is the leakage of room air out of a building.
[3] It is common practice to perform blower door tests at pressure differences on the order of 50 Pascals (ASHRAE, 2009).

differential is then recorded, normalized, and used to compare against industry benchmarks.

Figure 2.2: Blower door experiment set up in a UDB building

While most blower door measurements are made for whole building, single-zone situations, techniques exist for making component or multi-zone leakage measurements (Sherman and Dickerhoff, 1998). The three buildings investigated in this project were two-story, multi-zone buildings on the main UDB campus. To calculate the amount of infiltration in these buildings, I used methods developed by Lawrence Berkeley National Laboratory (LBL) that will be explained in the Methods section.

Since 1982, the Florida Solar Energy Center (FSEC) has been conducting research on strategies that can reduce the energy consumption of buildings in hot-humid climates. According to their work, the building envelope is where the most cooling loads occur, and effectively reducing the sensible and latent heat gains through the envelope is an essential step for minimizing air-conditioning energy consumption (Chasar, 2004).

The positive returns obtained from an energy-efficient envelope design can be seen in the results of a DOE-2 analysis of ten commercial high-rise buildings in the sub-tropical climate of Hong Kong. The study compared the effectiveness of various cooling strategies including air sealing, insulation, reflection, and shading. The results showed that the cooling energy consumption was as much as 35% lower in buildings that effectively utilized the cooling strategies than in the buildings where such strategies were not incorporated (Chan and Chow, 1998).

A common design strategy for reducing cooling demand in hot-humid climates is the implementation of cool roof surfaces. A cool roof uses high thermal emittance materials that reflect the sun's heat back to the sky. In an FSEC field study of seven identically built Florida homes with different roof constructions, it was found that the homes with reflective roofing benefited from as much as a 39% reduction in cooling demand (Parker, 2003). The materials used to construct a cool roof do not necessarily need to be complex. In the summer of 1994, FSEC simply whitened the existing roofs of nine Florida homes and found a 19% reduction in AC consumption (Parker, 2003).

An additional component of a cool roof can be a radiant barrier, which is essentially a sheet of reflective aluminum foil that is placed inside the attic space to prevent radiant heat gain. The University of Nevada Last Vegas' Energy Research Center compared the energy consumption of a Las Vegas home with a radiant barrier to a neighboring baseline home. The study concluded that the home with the radiant barrier consumed 4.6% less energy per year than the baseline home; the roof in the radiant barrier home cost 5.7% more to build than the roof of the baseline home and had a 9.5 year payback period (Zhu et al., 2009).

2.4 Air-Conditioners: Efficiency and Impact

When air conditioning is used in tropical climates, it typically represents the largest single energy expenditure in a building (FSEC, 2007). In a study of five air-conditioned buildings on the UDB campus, it was estimated that air conditioning composed 35-65% of each building's total energy consumption (Machado and Monroy, 2010). According to energy audit studies of residential homes in Florida, the most effective means of decreasing the cooling loads in existing buildings are with retrofits to roofs, windows, and duct systems (Parker and Sherwin, 2001). Due to the prevalent use of air conditioning in hot-humid climates, this project focused primarily on the possible methods for reducing the cooling loads of the buildings on the UDB campus.

The SEER (Seasonal Energy Efficiency Ratio) rating procedure was adopted by the US Department of Energy in 1979 to provide consumers with an indication of air conditioner efficiency (Federal Register, 1979). SEER value (e.g. SEER 10 or SEER 13) is defined as the total cooling energy delivered divided by the total electric energy input over a typical cooling season (Btu/W·hr). Higher SEER values indicate greater efficiency levels. In terms of energy consumption, an air conditioning unit with a SEER rating of 13 is 30% more efficient than a unit with a SEER rating of 10.

In January 2006, SEER 13 was established as the minimum allowable efficiency for air conditioners sold in the US (DOE EERE, 2006). However, in El Salvador, no standard currently exists that guarantees the efficiency of air conditioners available on the market. The purchase price of an air conditioning unit with a SEER rating of 10 is significantly less than that of a unit with the same cooling capacity and a SEER rating of

13. For this reason, air conditioners with SEER ratings of 10 or less are commonly installed in newly constructed Salvadoran buildings (Rivera, 2011).

The refrigerants used in air conditioning systems are an environmental concern as they commonly contain ozone-depleting CFCs (chlorofluorocarbons) and HCFCs (hydro chlorofluorocarbons). In 1987, the Montreal Protocol established requirements that began a worldwide phase out of CFCs and HCFCs (EPA, 2010a). Refrigerant-22 (R-22), which I found to be used as the heat exchange fluid in all 45 air conditioners reviewed at UDB, is among the substances to be phased out by 2020.

Additionally, a byproduct of R-22 production is HFC-23, which is a greenhouse gas (GHG) with a global warming potential (GWP) 11,700 times higher than that of CO_2 (EPA, 2011). While existing R-22-based systems can continue to be serviced with R-22 until 2020, the EPA recommends that the R-22 be recycled, reclaimed, or destroyed when the systems are serviced. The phase-out of R-22 will require that UDB convert to Montreal Protocol compliant systems by 2020, which presents an opportunity for UDB to upgrade to more efficient systems.

2.5 Energy Efficiency Efforts at other University Campuses

Many university campuses have recognized the need for reducing energy consumption in their buildings and have implemented various strategies to achieve this goal. This section provides a few examples of practices adopted by various U.S. universities that could possibly be transferred to UDB.

The Energy Dashboard project at the University of California San Diego (UCSD) has taken a novel approach to monitoring campus energy consumption. UCSD uses wireless current transducers to record energy use data that can be viewed in real-time from the UCSD website.[4] Allowing building occupants to view how much energy they are using in any given moment creates a conscious connection between the user and the energy they use. Additionally, monitoring energy use at a detailed level makes identifying energy losses and possible improvements easier.

Some universities have sought energy savings through regulation of campus building setpoints. The University of North Carolina at Chapel Hill is one such example, where they have initiated campus wide heating and cooling standards. For example, in the summer occupied buildings must be conditioned to 76 – 78 °F, and during winter building temperatures must remain between 69 – 71 °F (UNC, 2009). This type of mandate prevents building occupants from wasting energy by over-conditioning buildings.

Lastly, many universities attempt to reduce their carbon footprint through active student involvement in energy efficiency projects. HSU showcases this model with the Humboldt Energy Independence Fund (HEIF), which was developed in 2007 with the mission of reducing HSU's environmental impact (HEIF, 2011). HEIF is a fund maintained through the Instructionally Related Activities fees in HSU student tuition. These funds are distributed to student-driven projects in the fields of renewable energy and energy efficiency. Some of the past HEIF projects have included energy efficiency studies of buildings on the HSU campus, large-scale lighting retrofits, a 10.5 kW photovoltaic project, and a solar thermal project (Dorji, 2010).

[4] http://energy.ucsd.edu/

CHAPTER 3 METHODOLOGY

This chapter describes the methods that were used to carry out this project. The first step of this study was to assess UDB's energy usage by analyzing historic energy records and conducting walkthrough surveys of the buildings that lacked reliable metered energy data. The next step was to perform detailed audits of the three most energy intensive buildings using tools and instruments borrowed from the CIER. Part of the auditing process also involved the use of the DOE-2 software interface eQuest (Quick Energy Simulation Tool) to validate the retrofit options. The results from the eQuest models were used to complete economic analyses so as to recommend the most viable retrofit alternatives. Finally, my experience promoting energy efficiency education in El Salvador is discussed.

3.1 Building Selection Process

UDB technicians provided records from the campus electricity meters for 2009 and 2010. These records were corroborated by UDB's utility bills from CAESS (A subsidiary company of the American Energy Services (AES) Corporation) and provided a basis to rank the intensity of energy use in each building. Prior to this study, the data recorded from campus meters had not been digitized and little work had been done to analyze them.

Building energy efficiency studies performed on the HSU campus have used a prioritization strategy in order to identify the buildings that benefit most from retrofits (Dorji, 2010). In my study of the UDB campus, I implemented a similar system by creating a ranking of building energy intensities. This strategy not only helps to determine the buildings that have the highest savings potential, but it also can be used as a tool for future energy efficiency studies on campus. A ranking of campus building energy intensities can serve as a guideline for which buildings should be analyzed next, after more intensive buildings have been audited.

Only five of the 19 buildings on the UDB campus are equipped with reliable electricity sub-meters. The remaining 14 buildings have one of the three following characteristics: (1) they are equipped with a single meter that records the energy use of multiple buildings, (2) they have meters that are inaccurate according to the UDB technicians, or (3) they do not have a sub-meter installed. Fortunately, UDB has one meter that accurately records the energy consumption of the entire university campus. The readings from this all-inclusive campus meter were in agreement with the historic energy bills from the electricity provider CAESS, and therefore the meter was considered reliable. I was able to estimate values for the missing energy data by using the records of the master campus meter, in conjunction with a bin system that utilized parameters of Building Energy Usage Intensity (BEUI) in kWh/ft^2/year, and Building Energy Usage (BEU) in MWh/year.

The BEU and BEUI are important parameters that help determine key areas for building improvement efforts (Stroupe, 2010). I developed a strategy that allowed me to categorize the BEU and BEUI of all campus buildings despite UDB's incomplete energy records. In my strategy, I placed the BEU of every building with reliable data into one of three categories: high BEU (>100 MWh/year), medium BEU (20-100 MWh/year), and low BEU (< 20 MWh/year). The area (ft^2) of each building with reliable data was then recorded so as to place the energy usage in units of kWh/ft^2/year (BEUI). Each building without reliable meter data was then placed into the BEU category that I believed to be representative of its actual energy usage. I based this decision on the usage schedules and the number of air conditioning units in the building, as air conditioning typically represents the largest single energy expenditure for buildings in hot-humid climates (FSEC, 2007). Finally, for the buildings with unknown data, I multiplied the average BEUI (kWh/year/ft^2) of their respective BEU category by the building's gross area (ft^2) in order to arrive at figures of estimated kWh/year for all buildings on campus. With this process I was able to identify what are most likely UDB's three most energy intensive buildings as well as a total campus ranking of building energy consumption.

3.2 Walkthrough Survey and Detailed Analysis

For the three buildings I identified as most energy intensive, I performed technical energy audits and studied the materials and equipment within each building. I conducted interviews with building occupants and technicians in each building so as to become familiar with the maintenance histories and usage schedules.

All data were collected at UDB's main campus in Soyapango over a six-week period from June 6th to July 15th, 2011. The following instruments were used to collect data during the auditing process:

- A Retrotec R43 blower door to assess the amount of infiltration taking place in the building;
- An Onset HOBO U30 data logger to record weekly temperatures in selected rooms and attic spaces and provide estimates of when cooling equipment is used;

- A FLIR i5 thermographic camera to measure building envelope surface temperatures and thus estimate the amount of heat transfer taking place across the building envelope, and to also identify the heat leaks that result in excessive loss of conditioned air;
- An Extech Q527 light meter to measure the intensity of light received in the rooms and to verify if the rooms are over-lit; and
- A Watts Up? Pro power meter to detect the phantom loads that consume small amounts of electrical current while turned off.

The infiltration data provided by the blower door experiments were recorded in units of cubic feet (ft^3) per minute (cfm). In order to compare the infiltration values to ASHRAE standards and guidelines found in other building literature, I converted cfm to air changes per hour (ACH) (Equation 1).

$$\mathrm{ACH}_{50} = 60\left(\frac{\mathrm{cfm}_{50}}{\mathrm{V}}\right) \tag{1}$$

Where

ACH_{50} = Air changes per hour at 50 Pascals pressure difference

cfm_{50} = Infiltration rate at 50 Pascals pressure difference (cfm)

V = Volume of room (ft^3)

The pressure differential across a building will vary with the weather changes throughout the year. To compensate for the seasonal variation of ACH in the building, I used a method developed by the Lawrence Berkley National Laboratory (LBL). In the LBL infiltration model, a correlation factor “N” is calculated to account for the causes of infiltration that vary across climates, as well as characteristics that are unique to the building. The LBL infiltration model is approved by ASHRAE and is one of the most widely accepted techniques for estimating infiltration rates (Sherman, 1987). The annual average amount of ACH (i.e. seasonal ACH) is estimated using Equation 2 in conjunction with the correlation factor (Equation 3).

$$\text{Seasonal ACH} \approx \frac{\text{ACH}_{50}}{\text{N}} \tag{2}$$

Where

Seasonal ACH = Average ACH over the course of a year

N = Correlation factor as calculated by Equation 3

$$\text{N} = \text{C}\cdot\text{H}\cdot\text{S}\cdot\text{L} \tag{3}$$

Where

C = Climate factor

H = Building height correction factor

S = Wind shielding correction factor

L = Building leakiness correction factor

The tables I used to calculate parameters C, H, S, and L can be referred to in APPENDIX A. The LBL infiltration model only provides values for the climate factor C for geographical areas in the United States and Canada. To compensate for this lack of climate data, I used the C value for southern Florida, as it is the closest latitude band to San Salvador and the two locations had similar cooling degree day (CDD) patterns during 2011.

Finally, I developed estimates for the infiltration rates in each room of the building by extrapolating the ACH values that I calculated with the LBL infiltration model. The ACH values were calculated based on the estimated leakage areas (ELA) of the cracks in each room and the total wall area of each room. Using Equation 4, I was able to estimate the ACH for each room that wasn't tested with a blower door.

$$\mathrm{ACH_E} = \mathrm{ACH} \cdot \frac{(\mathrm{ELA_E}/\mathrm{A_E})}{(\mathrm{ELA}/\mathrm{A})} \tag{4}$$

Where

ACH_E = Estimated ACH in a room with an unknown infiltration rate

ACH = ACH in the blower door tested room, calculated with LBL model

ELA_E = Area of building openings (ft^2)

A_E = Total wall area (ft^2)

ELA = Area of building openings in the blower door tested room (ft^2)

A = Total wall area in the blower door tested room (ft^2)

Since 1958, the Illuminating Engineering Society (IES) has published illuminance standards for various indoor tasks and activities (Williams, 1999). I used the Extech Q527 light meter to measure illuminance levels at task planes. I also used the IES method to determine the proper amount of lighting in each room that I examined during the building audits. The IES method consists of a three-step process where the visual task and contrast is first defined, an illuminance range is selected based on the visual task and contrast, and the final illuminance is selected based on weighting factors such as occupant age, importance of speed, duration of task, and reflectance of task background (IESNA, 2001). The tables and procedure that I used to estimate proper lighting levels for UDB's rooms are given in APPENDIX B.

The UDB administration was not able to provide me with architectural plans for the buildings studied in this project. Due to the lack of information, all structural dimensions of the building zones and ductwork were measured by hand on site. Also, the compositions of building materials were determined via visual inspection and entry into attic spaces. A standard survey procedure was developed to document all building envelope information as required by eQuest parameters. Table 3.1 shows an example of a completed form for the Cisco Building.

Table 3.1: Example form for building material inspection

Component	Cisco Building Description
Frame	Metal frame, two story
Exterior Walls	6 inches heavy weight concrete block
Interior Walls	Wood frame 2x4 24 inch o.c. with ½ inch R-6 insulation
Roof	Corrugated zinc, with medium rust finish
Ceiling	Non-insulated lay-in acoustic panels
Ground Floor	Cement slab with Earth contact
Second Floor	4 inches light weight concrete with vinyl tile finish
Windows	3 mm louvered (Sol Aire)
Doors	Type 1) Steel with foam core
	Type 2) Steel without foam core

The data collected from the interviews, the building survey, and the data collected using the aforementioned instruments were used to create eQuest building models.

3.3 eQuest Modeling

Computer-based simulation is accepted by many energy efficiency studies as a reliable tool for evaluating building energy use and retrofit possibilities (James, 2000; Al-Homoud, 2001; and Zhu, 2006). While there are many simulation tools available (e.g. EnergyPro and Trace700), I chose eQuest to validate my retrofit recommendations. eQuest is a user interface for the industry standard DOE-2 computer program. I decided to use eQuest because it is a user friendly freeware program that offers a comprehensive set of features: eQuest predicts the hourly energy use and energy cost of a building given user-input information including hourly weather data, building layout, HVAC description, and utility rate structure (Crawley et al., 2005). With eQuest, a user can determine the combination of building parameters that best improves energy efficiency while maintaining thermal comfort. eQuest is also the software used at HSU for energy studies, which was an additional impetus for using the program. Using eQuest for energy studies at UDB would foster inter-university collaboration between HSU and UDB, and make comparisons of energy use between the two universities easier.

An essential part of an accurate eQuest model is a weather file that is representative of the annual climate in the building location. An eQuest weather file contains hourly data for solar radiation (Btu/hr·ft^2), dry and wet bulb temperatures (°F), cloud type, wind direction (rotational degrees), and wind velocity (knots) (Sailor, 2007). The weather file for this study was procured from the United States Department of Energy's Energy Efficiency and Renewable Energy (DOE EERE) website for the location of Ilopango Airport in San Salvador, El Salvador. The Ilopango weather station (latitude 13.41°N and longitude 84.07 °W) is approximately 2.9 miles away from UDB (latitude 13.42 °N and longitude 84.09 °W) (Figure 3.1), and it is assumed that the weather trends of the two locations are similar.

Figure 3.1: Map of university and weather station location[5]

In the model calibration process, I reasonably adjusted uncertain model parameters until the simulated outputs matched the monthly electricity bills within a ±10% margin of error. The standards and guidelines for acceptable tolerances of calibrated models vary from ±5% mean error per month (ASHRAE, 2002) to ±15% mean error per month (DOE, 2000). I chose ±10%, as it is a middle ground between the recommended tolerances.

When calibrating a building model it is essential to make justifiable changes to unknown parameters (i.e. occupancy schedules, set points, and infiltration) while leaving the known parameters (i.e. weather data and HVAC ratings) untouched. The occupancy schedules are difficult to predict as the day, time, and size of classes change on a semester-to-semester basis. I calibrated the models primarily with adjustments to the

[5] http://maps.google.com/maps

occupancy schedules and some alterations to equipment usage schedules and set points. Figure 3.2 shows the general logic flow diagram I utilized when calibrating the eQuest models.

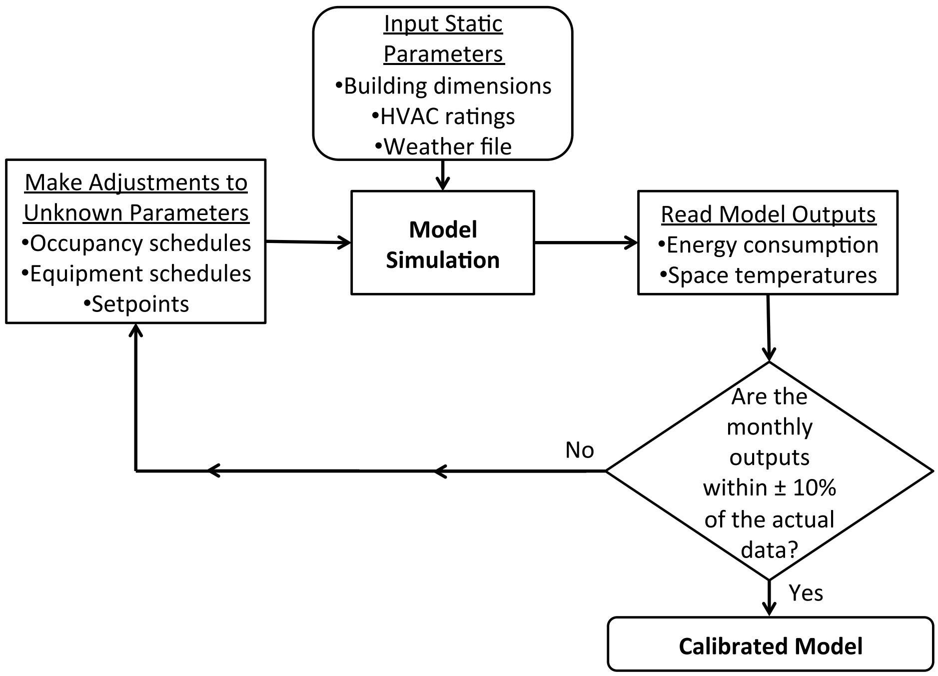


Figure 3.2: Logic flow chart for calibration process

Once the models were considered calibrated, I proceeded to test them for retrofit opportunities. The retrofits I tested focused on reducing the building's cooling load with cool roofs and reduced infiltration rates. I also tested the scenario of upgrading the building's cooling equipment to SEER 13 and SEER 16. Last, I modeled various combinations of these retrofits in order to observe how they interact with each other and to identify the highest energy savings options.

The cool roof retrofit was modeled in eQuest by changing the exterior finish color and the solar absorbance ratio, where the solar absorbance ratio is the fraction of incident solar radiation that is absorbed by the roof's surface. White lacquer was the color chosen to replace the existing medium rust paint that has an absorbance ratio of 0.71. The absorbance ratio that corresponds to white lacquer paint is 0.21 (DOE, 1979) and was used as the updated roof surface construction parameter in eQuest.

In order to further minimize the amount of radiant heat transfer between the hot roof surface and the building interior, a radiant barrier was also considered as a part of the cool roof retrofit. According to FSEC research in the southeastern United States, roof-mounted radiant barriers can reduce the annual electricity used for cooling in homes by 7-10% (Parker et al., 2001). A radiant barrier typically consists of a thin sheet of aluminized Mylar® attached to the underside of the roof; this material is not available in eQuest's default component library, so I followed literature from Texas A&M and used their values as inputs to simulate this retrofit in eQuest.

Researchers from Texas A&M University's Energy Systems Laboratory have modeled radiant barriers in eQuest (DOE-2) by implementing fictitious insulation layers with thermal resistance values suggested in the ASHRAE Handbook of Fundamentals (Seongchan and Haberl, 2007). According to their research, a material with an R-value of 8.1 (hr-ft^2-F/Btu) and an emittance (absorbance) value of 0.05, added to the interior roof construction of the eQuest model will effectively act as a radiant barrier. Following this research, I placed an additional layer of R-8 insulation with an absorbance of 0.05 in the second floor ceiling construction of each building model with a cool roof retrofit.

The upgrades to more efficient cooling equipment were modeled by making adjustments to the AC unit's coefficient of performance (COP). The COP is directly related to the cooling system's SEER rating with the key difference being that the COP is a unitless value. I calculated the unitless COP values for each cooling device by dividing the SEER rating by 3.412, which is the conversion factor from Btu to watt hours and results in the following equation:

$$\mathrm{COP} = \frac{\text{SEER value}}{3.412} \tag{5}$$

To model the SEER 13 retrofit the COP of all the current AC units was increased from 2.93 to a COP of 3.81, and to model the SEER 16 retrofit the COP was further increased to 4.61.

3.4 Economics

The retrofit possibilities found using eQuest were evaluated for their savings potential and long-term profitability through economic cash-flow analyses over a 20-year period. From 2005 to 2011, the average price of electricity in El Salvador increased by 8.9 percent per year on top of inflation (SIGET, 2011).[6] This six-year trend was the only information I had to develop a forecast of future electricity costs. Because the electricity cost escalation rate will likely deviate from 8.9 percent per annum during the next 20 years, I performed a sensitivity analysis on the future cost of electricity. The sensitivity analysis demonstrates how varying future electricity prices can affect the Net Present Value (NPV), and payback periods of each retrofit. The annual electricity cost escalation rates that I chose for the analysis were 0%, 3%, 6%, and 9%, where 3% was chosen as a conservative rate to represent the baseline scenario.

A discount rate of eight percent was calculated with assistance from the UDB Department of Economics, and was used to represent the time value of money (Bermudez, 2011). Price quotes for the materials and installation of each retrofit were

[6] From 2003-2010, El Salvador's average annual inflation rate was 4.1 percent (CIA, 2011b)

procured from various suppliers within the department of San Salvador so as to ensure that the parts and labor are locally available. Using Microsoft Excel, the NPV and payback period of each retrofit were then calculated to determine the most viable alternatives.

3.5 Promotion of Energy Efficiency Awareness

Throughout the data collection process, UDB engineering professor Wilfredo Monroy accompanied and assisted me in making various data measurements. The intention of having professor Monroy as my counterpart was for him to learn the methodologies and tools needed to complete the energy audit process and to utilize the experience in future energy efficiency projects at UDB. An additional objective of having professor Monroy's assistance was that more energy efficiency education would be disseminated to UDB students in the classroom setting.

A European study reported that the most effective means of reducing carbon emissions in the building sector is through informing and educating the general public about sustainable building practices (Fink, 2011). During the course of my stay in El Salvador, I gave several training workshops and speeches on the topic of energy efficiency. Some of the presentations were made to industry professionals (e.g., engineers and architects) and some were given to groups of UDB students. The presentations covered the impact of energy use in buildings and the tools that can be used to mitigate their carbon footprint. During one such workshop I gave to industry professionals, I presented an introductory lecture on eQuest modeling complete with hands on modeling exercises. It was hoped that this series of communications increased awareness of the importance of energy efficiency in buildings, raised interest in computer modeling as a tool for achieving energy efficiency in buildings, and initiated energy conscious behavior changes.

CHAPTER 4 RANKING OF BUILDING ENERGY INTENSITIES

The electric sub-meters on the UDB campus are not inclusive of all buildings on campus. This aggregation of energy monitoring over multiple buildings is not uncommon in colleges and universities; in fact, few university campuses have the energy metering equipment to measure the performance of their facilities on an individual building basis (EPA, 2007). A list of all UDB buildings (i.e., individually metered (Reliable), group metered (Grouped), and unmetered buildings (No Meter)) and the corresponding annual readings of the UDB sub-meters for 2010 are shown in Table 4.1.

Table 4.1: UDB campus meter readings (2010)

Building(s)	Meter Reading (MWh/year)	Meter Status	Building Area (ft^2)
Cafeteria	115.7	Reliable	3,000
Administration	47.1	Reliable	12,036
Professor Offices	23.5	Reliable	10,206
Soldering Workshop	14.3	Reliable	5,088
Museum	12.7	Reliable	19,064
Conventions Building	NA	No Meter	11,644
Large Lecture Hall C	NA	No Meter	21,060
Prosthetics Building 8	NA	No Meter	18,224
Library	NA	No Meter	13,706
Student Development	NA	No Meter	17,088
Cisco Building	340.8	Grouped	19,100
Mechanical Workshop			19,100
Studio Building	159.6	Grouped	10,165
Biomedical Building			19,100
Electronics Building 4			19,100
Small Lecture Hall A	58.5	Grouped	2,816
Large Lecture Hall A			16,575
Small Lecture Hall B	20.0	Grouped	2,816
Large Lecture Hall B			16,575
Total of Sub-meters	**792.2**	**NA**	**256,463**
Master Campus Meter	**964.8**	**Reliable**	**256,463**

The difference between the master campus meter and the sum of the available sub-meters is 172.6 MWh/year, or 17.9% of the metered campus total (Table 4.1), which is the amount of energy that needs to be allocated among the unmetered facilities in order to create a complete campus ranking of BEU and BEUI.

The meters with a status of "Grouped" (representative of two or more buildings) or "No Meter" presented challenges for developing a complete ranking of BEU and BEUI. To separate the meters labeled "Grouped" into individual readings, I performed a series of initial building walk-through audits. During these audits, I recorded the significant electric loads and their approximate usage schedules in order to estimate what percentage of energy is consumed by each building in the grouped sub-meter configurations. The results of the walk-through audits were used to generate an updated list of energy intensities as shown in Table 4.2.

To account for the buildings with no metered data, the BEUs in Table 4.2 are distributed into one of three classes: high (>100 MWh/year), medium (20-100 MWh/year), and low (< 20 MWh/year). As detailed below for each facility, the four buildings with unknown BEU are placed into the BEU class that is expected to be representative of the building's energy use (Table 4.3).

The student development building was placed in the low BEU category, as the building currently has no air-conditioning units installed and the building occupancy schedule is similar to those of the Museum and Library. The Convention Building, Prosthetics Building 8, and Large Lecture Hall C were placed in the medium BEU category, due to their moderate use of air-conditioning, which is similar to usage schedules of the Large Lecture Hall A and Biomedical Building.

Table 4.2: BEU after separating grouped meters

Building	BEU (MWh/year)	BEU Class	BEUI (kWh/year·ft^2)
Mechanical Workshop	217.7	High	11.3
Cisco Building	123.1	High	6.3
Cafeteria	115.7	High	38.6
Studio Building	105.4	High	10.4
Large Lecture Hall A	55.4	Medium	3.3
Administration	47.1	Medium	3.9
Biomedical Building	37.1	Medium	1.9
Professor Offices	23.5	Medium	2.3
Electronics Building 4	17.0	Low	0.9
Large Lecture Hall B	16.8	Low	1.0
Soldering Workshop	14.3	Low	2.8
Museum	12.7	Low	0.7
Library[7]	12.0	Low	0.9
Small Lecture Hall A	3.2	Low	1.1
Small Lecture Hall B	3.2	Low	1.1
Student Development	Unknown	NA	NA
Prosthetics Building 8	Unknown	NA	NA
Large Lecture Hall C	Unknown	NA	NA
Conventions Building	Unknown	NA	NA

Table 4.3: Estimation of unknown BEUs

Building	Estimated BEU Class	Average BEUI of BEU Class (kWh/year·ft^2)	Building Area (ft^2)	Estimated BEU (MWh/year)
Student Development	Low	1.2	17,088	20.7
Prosthetics Building 8	Medium	2.9	18,224	52.8
Large Lecture Hall C	Medium	2.9	21,060	61.1
Conventions Building	Medium	2.9	11,644	33.2
Total	**NA**	**NA**	**68,016**	**167.8**

The estimates of BEU in Table 4.3 complete the comprehensive ranking system of BEU and BEUI (Table 4.4). The total estimated BEU in Table 4.3 (167.8 MWh/year) closely matches the 172.6 MWh/year that was unaccounted for in Table 4.1. It should be emphasized that the results presented in Table 4.4 are based on several approximations

[7] Because the equipment in the library is limited to simple on/off loads (i.e. lights and fans), the energy consumption of the building was estimated by means of a walk-through survey instead of the bin system.

and postulates (i.e. the bin strategy of categorizing buildings into high, medium, and low energy use classes and separating grouped buildings with a walk-through survey), and therefore are not definitive. The ranking list is intended to serve as a preliminary guide in developing UDB's energy efficiency plan and to identify which buildings are the highest priority candidates for energy efficiency measures.

Table 4.4: Total combined building ranking system

Building	BEUI (kWh/year·ft^2)	BEUI Rank	BEU MWh/year	BEU Rank	Combined Rank
Mechanical Workshop	11.5	2	217.7	1	1
Cafeteria	38.6	1	115.7	3	2
Cisco Building	6.3	4	123.1	2	3
Studio Building	10.4	3	105.4	4	4
Large Lecture Hall A	3.3	6	55.4	6	5
Large Lecture Hall C	2.9	7	61.1	5	6
Administration	3.9	5	47.1	8	7
Prosthetics Building 8	2.9	9	52.8	7	8
Conventions Building	2.9	8	33.2	10	9
Biomedical Building	1.9	12	37.1	9	10
Professor Offices	2.3	11	23.5	11	11
Student Development	1.2	13	20.7	12	12
Soldering Workshop	2.8	10	14.3	15	13
Large Lecture Hall B	1.0	16	16.8	14	14
Electronics Building 4	0.9	17	17.0	13	15
Small Lecture Hall A	1.1	14	3.2	18	16
Small Lecture Hall B	1.1	15	3.2	19	17
Library	0.9	18	12.0	17	18
Museum	0.7	19	12.7	16	19
Total	**3.8**	-	**967.6**	-	-

Both BEU (MWh/year) and BEUI (kWh/year·ft^2) were considered when developing the combined rank in order to avoid investing in energy conservation measures (ECMs) for buildings that have high energy intensities, but small energy uses. The combined rank was calculated by simply adding the BEUI and BEU ranks and then sorting those values; priority was given to BEUI over BEU in the case where the combined rank (i.e. BEUI plus BEU) of two respective buildings was equal.

4.1 Building Energy Use Intensity (BEUI)

Based on energy intensity measured in units of kWh/year·ft^2, the Cafeteria has the highest energy consumption per ft^2 with 38.6 kWh/year·ft^2, while the Museum has the lowest rank at 0.7 kWh/year·ft^2. The high BEUI in the Cafeteria is explained by a large amount of cooking and refrigeration equipment concentrated in a small space. The average BEUI for the campus is 5.1 kWh/year per square foot of occupied building space.

4.2 Building Energy Use (BEU)

The highest overall energy user on the UDB campus is the Mechanical Workshop consuming approximately 217.7 MWh/year, and the smallest energy users are Small Lecture Halls A and B, each consuming roughly 3.2 MWh/year. The average BEU is 50.9 MWh/year per building.

The all-inclusive campus sub-meter indicates that 964.8 MWh/year is the total energy consumption of all buildings on campus (Table 4.1), which differs from the total BEU in Table 4.4 (967.6 MWh/year) by 0.3%. This discrepancy is due to the imprecision of the BEU estimates using the bin strategy.

4.3 Combined Ranking

The three most energy intensive buildings on the UDB campus are (1) the Mechanical Workshop, (2) the Cafeteria, and (3) Cisco Building. However, this project did not consider the Cafeteria as one of the buildings for in depth audit and study.

The decision to exclude the Cafeteria from detailed analysis was because tenants rent the restaurant spaces in the Cafeteria. The property owner-renter relationship commonly creates barriers to implementing energy conservation measures (ECMs) in rented buildings, known as split incentives. Split incentives frequently occur in rented buildings when the decision-maker does not receive many benefits from energy efficiency improvements (Fuller et al., 2009). In the case of implementing ECMs for the UDB Cafeteria, the University would invest in the building upgrades and not receive the reimbursement incentives because the restaurant tenants bear the energy costs.

In order to avoid the possible complications with split incentives and to maintain this project's focus on energy efficiency measures for my client, UDB, the Studio Building was chosen as the third building to include for in depth study. In the end, the three buildings I chose for in depth study and investigation of ECMs were the Mechanical Workshop, the Cisco Building, and the Studio Building (Figure 4.1).

Figure 4.1: Map of UDB campus with energy intensive buildings (Google Earth image)

CHAPTER 5 MECHANICAL WORKSHOP

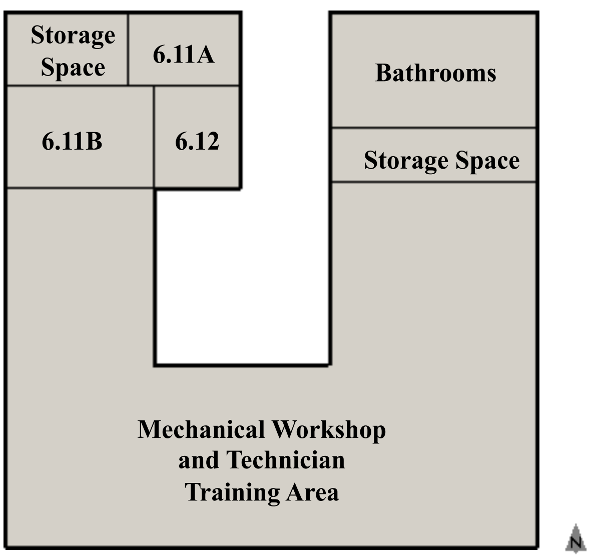
The Mechanical Workshop (known as *El Taller Mecánico* in Spanish) was found to be the largest overall consumer of electricity and the second largest consumer of electricity on a per square foot basis. In this section, I present an overview of the energy uses and wastes in the Mechanical Workshop as well as the recommended ECMs per eQuest modeling. The feasibility of each recommended ECM is explained in economics section 9.2.

5.1 Building Description

The Mechanical Workshop is a two-story building with a gross area of 19,100 ft^2 located in the southwest corner of campus. The building was constructed in 1992 and over the years several split type air conditioning units have been added to the second floor (Aleman, 2011). The first floor serves primarily as a workshop and laboratory for mechanics and technician students, but also contains a few classrooms for lectures (Figure 5.2 and Figure 5.3). The occupancy schedule on the first floor varies by academic semester, but is occupied approximately 16-30 hours a week (Vasquez, 2011). During occupied hours, the use of the workshop equipment varies depending on class subject matter and class size.

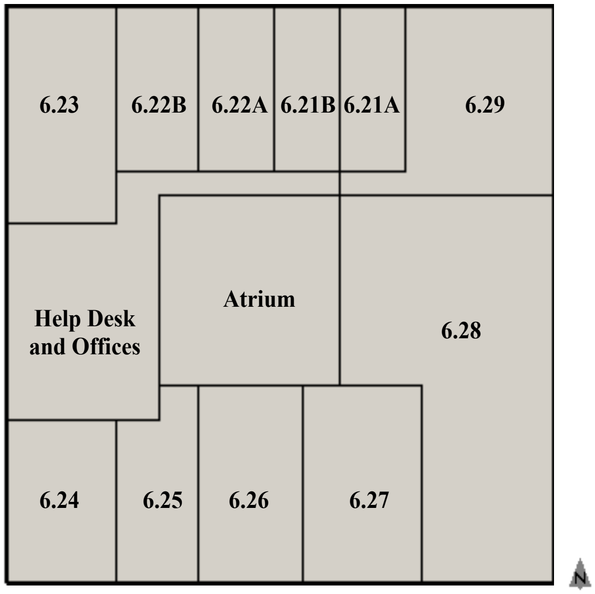
The functions on the second floor are divided into nine computer labs, the campus server room, and the hydraulics laboratory (Figure 5.3). The computer labs and campus server room are the most energy intensive zones on the second floor as they are air-conditioned, and contain between 10 and 30 computers each. The zones on the second floor are occupied 15 to 40 hours a week depending on semester (Vasquez, 2011).

Figure 5.1: Mechanical Workshop (facing south)



Room	Description
6.11A	Mechanics Lab
6.11B	Mechanics Lecture Room
6.12	Mechanics Lab

Figure 5.2: Mechanical Workshop first level floor plan



Room	Description
6.21A	Classroom and Open Computer Lab
6.21B	Classroom and Open Computer Lab
6.22A	Classroom and Open Computer Lab
6.22B	Classroom and Open Computer Lab
6.23	Classroom and Open Computer Lab
6.24	Classroom and Open Computer Lab
6.25	Classroom and Open Computer Lab
6.26	Classroom and Open Computer Lab
6.27	Classroom and Open Computer Lab
6.28	Hydraulics Laboratory
6.29	Campus Servers

Figure 5.3: Mechanical Workshop second level floor plan

The building envelope consists of a metal frame and six inches of heavy weight concrete for both the exterior and interior walls. The first floor height is 13 feet with two feet of plenum space between the first and second floor. The floor to ceiling height on the second floor is 10 feet. The flooring on the first floor is a concrete slab and on the second floor the flooring is vinyl tile placed on four inches of lightweight concrete. The roof surface is lined with corrugated metal panels that have a medium rust color. In the attic space there is R13 fiberglass insulation unevenly placed above an acoustic panel ceiling. The exterior doors are steel, some of which have an added layer of urethane foam for insulation (Figure 5.4). The windows are 3mm single pane with aluminum frames; some of the windows are louvered to allow for user-controlled passive cooling.

Figure 5.4: Exterior wall construction (top left), corrugated metal roof (top right), steel door with urethane foam (bottom left), and poorly installed insulation in the attic (bottom right).

5.2 Energy Uses

Electricity is the only form of energy supplied to the Mechanical Workshop. The energy consuming equipment is separated into three categories: (1) air conditioning, (2) plug loads (computers, servers, and shop equipment), and (3) lighting.

5.2.1 Air Conditioning System

Thirteen split AC units cool the computer labs on the second floor and have a collective cooling capacity of 44.25 tons. There is one AC unit per computer lab and four

AC units to serve the Help Desk, Offices, and Campus Servers. Only the Help Desk and Offices have ducted return air paths; the remaining zones are ductless. There are no air conditioners installed on the first floor as all the spaces are passively cooled. The cooling capacities of each AC unit and corresponding zone are shown in Figure 5.5.

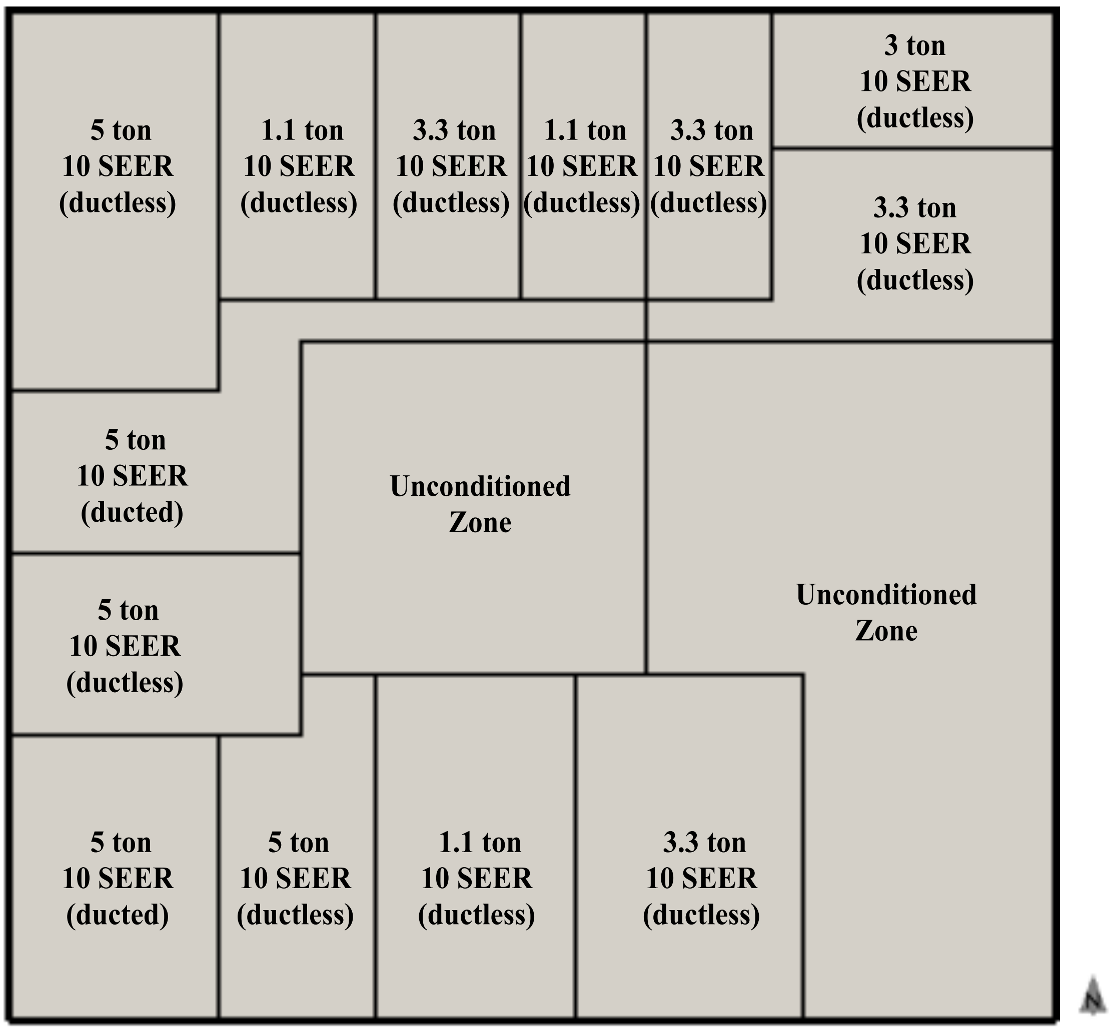


Figure 5.5: AC zone allocations and specifications (second floor)

5.2.2 Plug Loads

When all loads are turned on, the estimated equipment power density of the first floor is 6.5 W/ft^2 (the total area of the first floor is 8,350 ft^2). The most energy intensive loads are the workshop machines such as: compressors, motors, drill presses, grinders, band saws, and other fabrication machines. It is determined that there is no savings potential for the plug loads on the first floor as they are an essential part of the course curricula and have non-elastic usage demands.

The estimated power density of the second floor is 5.9 W/ft^2. The most significant loads on the second floor are the 240 computers in the labs and offices, the campus internet servers, and a 16 kVA uninterruptible power supply (UPS). The UPS ensures that power is supplied to the computers and campus internet servers in the event of a power failure. The UPS runs 24 hours a day, 7 days a week in order to support the campus internet servers, which are critical loads.

5.2.3 Lighting

The majority of the lights in the Mechanical Workshop Building are 32-watt T8 Fluorescent tubes. There are a few incandescent bulbs on the balcony, which are used sparingly, and one 250-watt metal halide bulb in the atrium, which is kept on during the nights. The total lighting power density on the first floor is 0.74 W/ft^2, and the lighting power intensity for the second floor is 0.87 W/ft^2.

The Campus Server room has the most intense lighting at an average of 366 lux. The most sparsely lit room in the building is computer lab room 6.27 with an average of 159 lux. The average lighting intensity of all rooms in the building is 269 lux.

5.3 Energy Losses and Audit Highlights

The walkthrough audits and building study revealed that there are four causes of energy waste: (1) excessive infiltration of outside air into conditioned zones, (2) heat gain through ceilings and walls, (3) over lit areas, and (4) out-of-date cooling equipment.

5.3.1 Infiltration

The blower door tests revealed that there are two main sources of outside infiltration into the conditioned rooms of the Mechanical Workshop Building: (1) crack spaces under perimeter doors, and (2) the louvered windows installed in rooms 6.26, 6.27, and in the Help Desk and Office area (Figure 5.6). There are also a few leaks and cracks in some ceiling panels, which likely cause additional infiltration of unconditioned air. Unfortunately, these ceiling leaks could not be measured empirically with blower door tests, as the ceiling is not sufficiently strong for an individual to walk on top and cover the leak (Figure 5.7). Additional leaks exist underneath interior doors, but are not considered significant as they permit air exchange between conditioned zones.

Figure 5.6: Example of crack space below perimeter doors (left), and louvered windows (right).

Figure 5.7: Ceiling panel leaks in room 6.22A/B (left), and crack spaces below interior doors (right)

One blower door test was performed in room 6.22A/B to determine the amount of air infiltration through the crack spaces below the perimeter doors.[8] Only two rooms in the Mechanical Workshop Building are suitable to test the leakiness of the louvered windows with a blower door (Rooms 6.26 and 6.27). Due to the class scheduling conflicts in these rooms, a second blower door test was performed in room 5.10 of the adjacent Cisco Building to calculate the amount of infiltration that results from the louvered windows. Table 5.1 and Table 5.2 illustrate the results from both experiments.

Table 5.1: Blower door test results with fenestration uncovered

Test Room	Fenestration Tested	Correlation Factor "N"	Volume (ft^3)	Cfm_{50}	ACH_{50}	Seasonal ACH
6.22A/B	Perimeter Cracks	18.0	7,225	8,800	73.1	4.1
Room 5.10 (Cisco Building)	Louvered Windows	18.0	2,977	1,100	22.2	1.2

Building tightness factors (i.e. leaky or tight) and corresponding levels of ACH_{50} vary by climate, building size, and building age. However, generally speaking, houses

[8] There is a moveable partition that separates rooms 6.22A and 6.22B. The partition was removed for the blower door test, which resulted in a larger room space (room 6.22A/B).

with less than 5-6 ACH_{50} are considered tight, and those over 20 ACH_{50} are leaky (Keefe, 2010). Under these guidelines, both of the test rooms are leaky and in need of air sealing.

Table 5.2: Blower door test results with all fenestrations covered

Test Room	Fenestration Tested	Cfm_{50}	ACH_{50}	Seasonal ACH
6.22A/B	Perimeter Cracks	6,400	53.1	3.0
Room 5.10 (Cisco Building)	Louvered Windows	100	2.0	0.1

The seasonal ACH in the test rooms decrease when the fenestrations are covered (Table 5.2). The seasonal ACHs in Table 5.2 are considered the potential infiltration levels if the fenestrations were sealed. In the case of Room 5.10, the infiltration is reduced to 0.1 ACH when the windows are sealed. According to ASHRAE standard 62, buildings without forced air ventilation require 0.35 ACH or higher in order to prevent what is known as "sick building syndrome" (SBS), where building occupants suffer from poor indoor air quality and inadequate ventilation (EPA, 2010b). Therefore, the building envelope should not be made overly tight when sealing fenestrations.

The blower door data were extrapolated to the remainder of the building based on the estimated leakage areas (ELA) in each conditioned room (Equation 4). The data in Table 5.3 are projections of the present infiltration levels in the Mechanical Workshop Building. These data were ultimately used as the infiltration parameters for the baseline eQuest model of the building.

Table 5.3: Extrapolated infiltration data for the Mechanical Workshop building

Room	Crack Area (ft^2)	Wall Area (ft^2)	Crack Coverage	Window Area (ft^2)	Window Coverage	Window Type	Seasonal ACH
6.21 A/B	0.56	1,055	0.05%	51	4.8%	Sealed	4.1
6.22 A/B	0.56	1,075	0.05%	53	4.9%	Sealed	4.1
6.23	0.38	1,103	0.03%	150	13.6%	Sealed	2.6
6.24	0.19	947	0.02%	144	15.2%	Sealed	1.5
6.25	0.38	860	0.04%	21	2.4%	Sealed	3.4
6.26	0.19	862	0.02%	120	13.9%	Louvered	2.7
6.27	0.19	1,094	0.02%	108	9.9%	Louvered	2.0
6.29	0.19	1,226	0.02%	144	11.7%	Sealed	1.6
Help Desk	0.56	2,240	0.03%	226	10.1%	Louvered	2.6
Room 5.1	0.375	630	0.06%	111.5	17.7%	Louvered	1.2

5.3.2 Heat Gain

Thermographic imaging and datalogger readings revealed two principal locations where excessive heat enters the Mechanical Workshop Building: (1) the roof and attic spaces, and (2) the steel doors on the perimeter of the building. The most significant sources of heat gain are through the roof and attic as these spaces are directly exposed to the sun throughout the day (Figure 5.8).

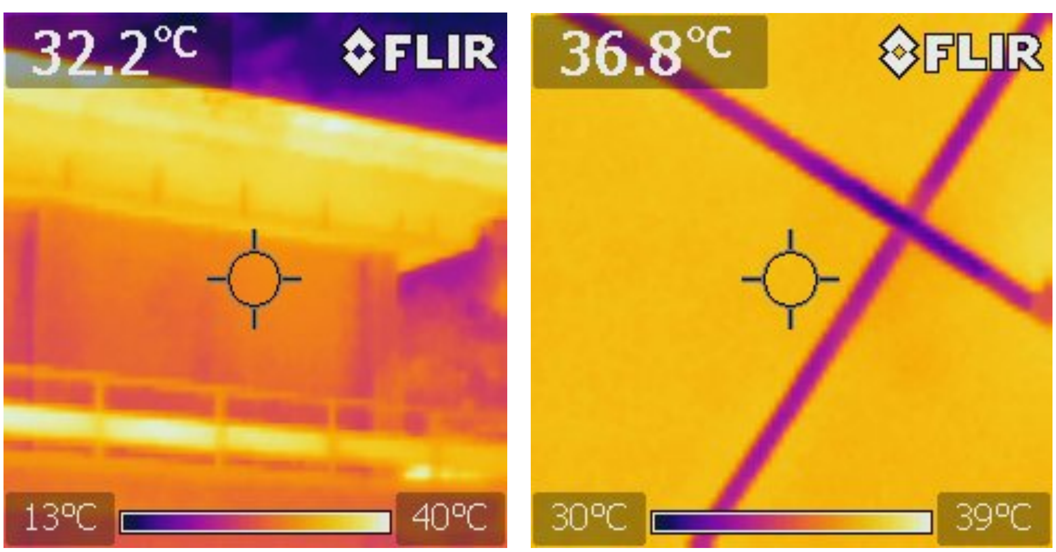


Figure 5.8: Thermographic images displaying the high surface temperatures of the metal roof (left) and the second floor ceiling (right). Outside air temperature was recorded as 77 °F (25 °C).

The photos in Figure 5.8 were taken at midday (12:00-12:30 PM CST) on June 23rd; the outside air temperature during that time was recorded as 77 °F. The surface temperature of the roof is approximately 104 °F, which is 27 °F hotter than the outside air. The surface temperature of the second floor ceiling is roughly 99 °F. The small difference between the surface temperature of the roof and ceiling shows that the majority of the heat absorbed by the aluminum roof is directly transferred into the classrooms and offices. This large amount of heat transfer demonstrates the need for implementing either a heat barrier or improved ventilation within the attic space of the Mechanical Workshop Building.

A datalogger with a temperature sensor was placed in the attic for a one-week period (June 18th to 24th, 2011) to measure the heat intensity in the space over time. The data showed an average temperature of 96 °F during the hours of 9AM-5PM and a peak temperature of 113 °F occurring at 1:15PM on June 23rd (APPENDIX C). The average high outside temperature for the week was 77 °F.[9] These measurements imply that on average, the attic space is significantly hotter than the outside air. The consistent high temperatures within the attic undoubtedly provoke excessive energy consumption by forcing the AC units to run for longer time periods in order to remove warm air from the building.

The steel doors on the perimeter of the building are also concerns for heat gain into the Mechanical Workshop Building (Figure 5.9). Some of the doors have already been lined with an extra layer of insulation. It is recommended that all doors be

[9] http://www.tutiempo.net/en/Climate/San_Salvador_Ilopango/06-2011/786630.htm

retrofitted to include a layer of insulation as well as reflective paint coatings (similar to the cool roof retrofit) so as to reduce the cooling load in the conditioned rooms.

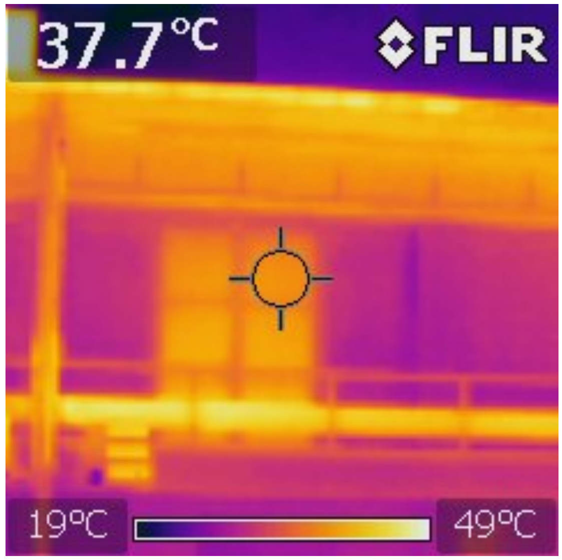


Figure 5.9: High surface temperature of an exterior steel door (Room 6.23). Outside air temperature was recorded as 77 °F (25 °C).

5.3.3 Lighting

Following the Illumination Engineering Society (IES) method, 300 lux is the illuminance level that will permit the occupants in the computer labs and offices to productively accomplish their required tasks. Out of the twelve rooms on the second floor, nine were measured for their lighting intensity. The luxometer readings showed that seven rooms in the building are over lit and two are under lit (Table 5.4), the remaining rooms in the building were not measured because the rooms were either occupied or access could not be obtained at the time the experiment was conducted. There is potential to reduce electric energy consumption in the Mechanical Workshop Building by reducing the lighting in the over lit rooms to appropriate illuminance levels.

Table 5.4: Recommended illuminance levels and lux readings

Room	Recommended lux per IES Method	Average lux Reading	Status
6.21 A/B	300	267	No Replacement
6.22 A/B	300	316	No Replacement
6.23	300	281	No Replacement
6.24	300	247	No Replacement
6.25	300	290	No Replacement
6.26	300	355	Over Lit
6.27[10]	300	159	No Replacement
Servers	300	366	Over Lit
Help Desk[11]	300	172	No Replacement

The lighting fixtures installed in the Mechanical Workshop Building each use four, 32-watt T8 fluorescent tubes (Figure 5.10). There are strategies that can be implemented with these fixtures to reduce energy consumption, mainly by decreasing overall lighting density. Furthermore, removing some of the lights will lower the amount of heat gain in the rooms and reduce the cooling demand.

Figure 5.10: Example of the lighting fixtures installed in the Mechanical Workshop Building

[10] Room 6.27 has two lighting fixtures out, which result in lower illuminance levels.
[11] The Help Desk floor to ceiling height is approximately 2 ft. higher than the other rooms and causes lower illuminance levels.

In June 2011, UDB staff member Mauricio Gomez tested the illuminance levels of an energy efficient lighting fixture in the Biomedical Building. The lighting fixture consisted of two 32-watt T8 tubes suspended by a reflective diffusor. The energy efficient lighting fixture resulted in a 20% decrease in lux and a 40% decrease in electric energy consumption when compared to the currently installed fixtures (Gomez, 2011). The details on how to perform a complete lighting retrofit in the Mechanical Workshop Building are discussed in APPENDIX D and the feasibility of the retrofit is described in APPENDIX E.

5.3.4 Cooling Equipment

All 13 AC units in the Mechanical Workshop Building are rated at SEER 10; these AC units are considered very inefficient by today's standards. The American Council for an Energy Efficient Economy (ACEEE) recommends consumers in all climates purchase new cooling equipment of SEER 14.5 or higher (ACEEE, 2011). Unfortunately in El Salvador, SEER 13 is the most efficient AC unit widely available on the market. While it is possible to purchase cooling equipment with a SEER of 16, the equipment is typically only available in small cooling capacities (i.e. one or two tons) (Rivera, 2011). The feasibility analysis for upgrades to SEER 13 and SEER 16 is discussed in section 9.2.

Many of the AC units installed in the Mechanical Workshop Building are exposed to direct sunlight throughout the entire day (Figure 5.11). This setup decreases both the efficiency and the life expectancy of the AC units. The estimated energy savings achieved from AC shading vary from 2-10%, depending on the shading structure's ability to cool the air that comes in contact with the AC condenser (Parker et al., 1996). While it is important that the AC unit be installed in a shady area, it is equally important that the chosen location does not impede the natural airflow to the AC condenser.

Figure 5.11: AC units located in direct sunlight

CHAPTER 6 CISCO BUILDING

The Cisco Building was found to be the second largest overall consumer of electricity, and the fourth largest consumer of electricity on a per square foot basis. In this section, I present an overview of the energy uses and wastes in the Cisco Building as well as the recommended ECMs per eQuest modeling. The feasibility of each recommended ECM is explained in economics section 9.3.

6.1 Building Description

The Cisco Building is a two-story building located a few yards northeast of the Mechanical Workshop (Figure 6.1). The building was constructed in 1994; one major remodel of the first floor was done in 1999 where insulated interior walls and a duct system were added to meet the cooling needs of the Metrology department. The building has an identical footprint and equivalent gross area (19,100 ft^2) as the Mechanical Workshop, but the room dimensions vary in the two buildings.

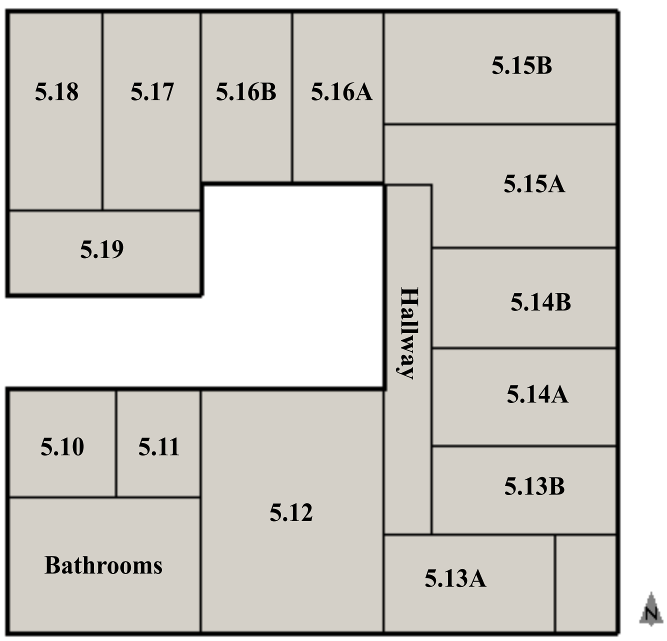
Figure 6.1: Cisco Building (taken from the second floor of the Mechanical Workshop)

The building construction materials are almost identical to those of the Mechanical Workshop.[12] The Cisco building has three distinct differences in construction from the Mechanical Workshop: (1) the interior walls on the first floor have wooden frames with fiber board sheathing in place of concrete walls, (2) the insulation above the second floor ceiling is evenly placed, and (3) all windows in the building are louvered.

The first floor is the center of operations for the Metrology department (Figure 6.2). The Metrology department consists mostly of laboratories that are used for experimentation 10-16 hours per week during the semester. The accuracy of the instruments in the labs is temperature sensitive, and therefore the labs are cooled to 68 °F when occupied. Two construction strategies have already been implemented to retain the

[12] Refer to section 5.1 for information on the material construction of the Mechanical Workshop Building.

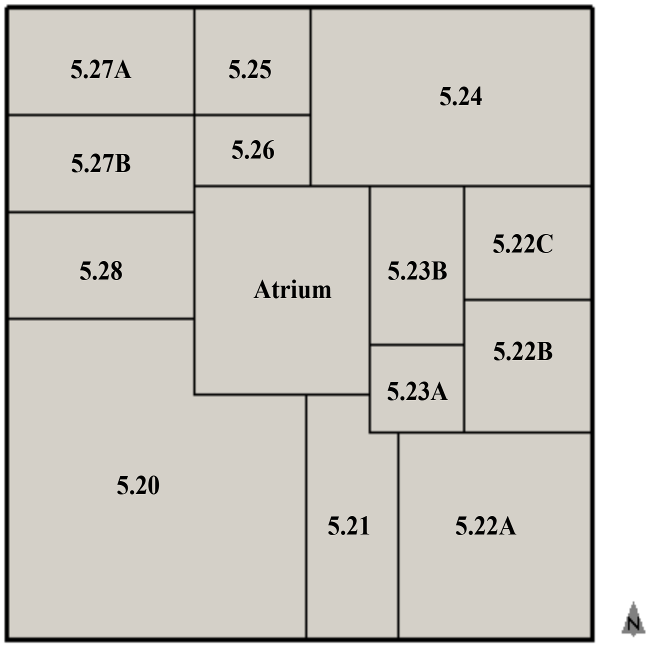
conditioned air and maintain the accuracy of experiments: (1) no windows in the labs, and (2) a double door vestibule to regulate infiltration into the labs. The demand for cooling in the Metrology department is more consistent in the offices than in the labs; the offices are typically conditioned to 70 °F during the 40-50 hour workweek and are occupied by 3-5 people (Nuila, 2011).



Room	Description
5.10	Faculty Office
5.11	Storage Room
5.12	Metrology Offices
5.13A	Physical Testing
5.13B	Thermometer Lab
5.14A	Pressure Lab
5.14B	Volume Lab
5.15A	Dimension Lab
5.15B	Weights and Balances Lab
5.16A	Non-Destructive Testing
5.16B	Fog Camera
5.17	Heat Treatment
5.18	Metrology Lecture Hall
5.19	Spectroscopy Lab

Figure 6.2: Cisco Building first floor layout

The functions of the second floor are divided into computer labs, faculty office zones, lecture rooms, and storage spaces (Figure 6.3). The most energy intensive rooms on the second floor are the three Cisco computer labs, and offices 5.21 and 5.25. The Cisco labs contain 15-20 computers each and are conditioned at 70-72 °F, 16-24 hours a week during the academic semester (Vasquez, 2011). Offices 5.21 and 5.25 are typically occupied by 2-4 people 40-50 hours a week and have regular cooling demands of 68-72 °F. Office 5.21 is located on the southern side of the building and slightly more prone to heat gain than office 5.25.



Room	Description
5.20	Education Department
5.21	CISCO Office
5.22A	CISCO Computer Lab 1
5.22B	CISCO Computer Lab 2
5.22C	CISCO Computer Lab 3
5.23A	Break Space
5.23B	Continued Education Office
5.24	Lecture Hall
5.25	Offices
5.26	Waiting Room
5.27A	Technical Training Lab 1
5.27B	Technical Training Lab 2
5.28	Storage Room

Figure 6.3: Cisco Building second floor layout

6.2 Energy Uses

Like the Mechanical Workshop, electricity is the only form of energy supplied to the Cisco Building. The energy consuming equipment in the Cisco Building is separated into three categories: (1) air-conditioning, (2) plug loads (computers and lab equipment), and (3) lighting.

6.2.1 Air Conditioning System

Seventeen AC units cool the building and have a cumulative cooling capacity of 63.1 tons. The AC fleet consists of 12 ductless split type systems, four ducted systems in the Metrology department, and one five ton system that has not functioned in over a year (Figure 6.4 and Figure 6.5). All AC units have low efficiency values of SEER 10.7 or less.

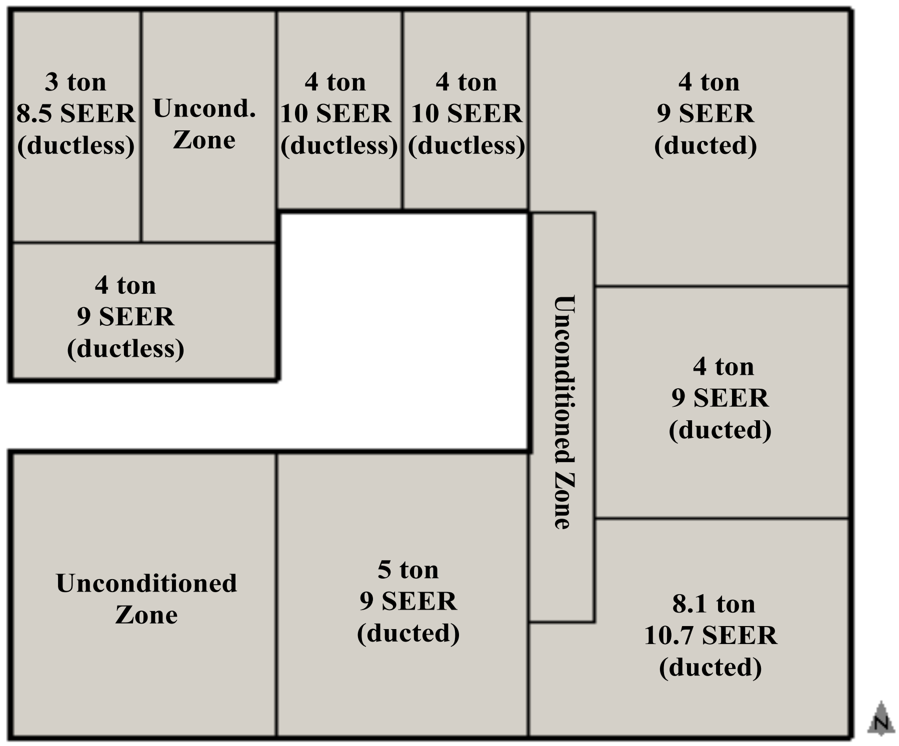


Figure 6.4: AC specifications and zone allocation (first floor)

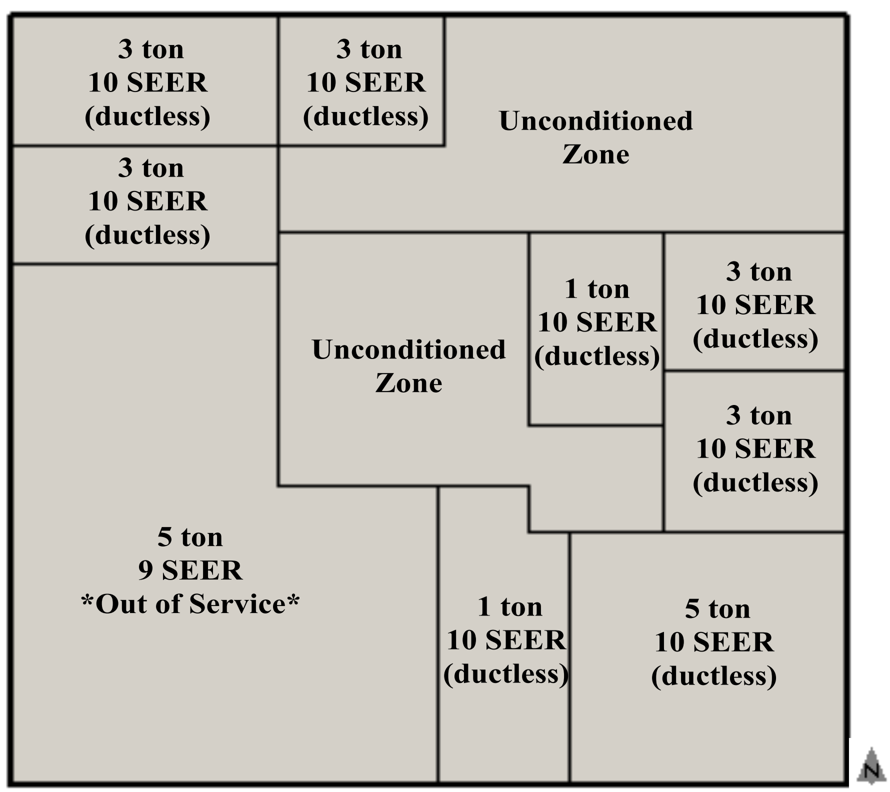


Figure 6.5: AC specifications and zone allocation (second floor)

6.2.2 Plug Loads

When all loads are turned on, the estimated equipment power density on the first floor is 0.9 W/ft^2 (the total area of the first floor is 8,350 ft^2). The most energy intensive loads are the computers and laboratory equipment (oscilloscopes, microscopes, pneumatic scales, and balances). The laboratory equipment in the Cisco Building is similar to the shop equipment of the Mechanical Workshop in that the devices have inelastic usage demands and is thus ineligible for energy savings with the exception of a few phantom loads that were identified (APPENDIX D).

The power density of the second floor is 2.4 W/ft^2 when all loads are turned on. The most significant plug loads on the second floor are the lab computers that are used 16-20 hours a week for systems and networking courses. There are roughly 15 faculty and staff computers that are used 40 hours a week.

6.2.3 Lighting System

The majority of the lights in the Mechanical Workshop Building are 32-watt T8 fluorescent tubes with the exception of one 250-watt metal halide bulb in the atrium, which is kept on during the night. 1.07 W/ft^2 is the total lighting power density on the first floor and 0.73 W/ft^2 is the power density for the second floor.

The Physical Test Laboratory (room 5.13A) has the most intense lighting at an average of 723 lux. Higher light intensities are required in the Metrology laboratories as many of the experiments involve visually focusing on small objects for extended periods of time. It is worth mentioning that over lighting can be prevented in these rooms by using task lighting to meet the lighting needs for visually intensive tasks. A list of all lux readings and recommended illuminance levels per the IES method are given in

APPENDIX D. The average light intensity in all Metrology labs is 568 lux. The most sparsely lit room in the building is Cisco computer lab 2 with an average of 235 lux. The average lighting intensity of all rooms in the building is 472 lux.

6.3 Energy Losses and Audit Highlights

The energy losses found in the Cisco building were similar to those found in the Mechanical Workshop. The similarity is not surprising as the two buildings have similar constructions and are prone to losing energy from the same design shortcomings. Study of the Cisco building revealed that there are four sources of energy waste: (1) excessive infiltration of outside air into conditioned zones, (2) out-of-date cooling equipment, (3), over-lit areas, and (4) phantom loads from computers and monitors.

Heat transfer from the roof is not as much an issue in the Cisco building as in the Mechanical Workshop. The majority of the cooling demand in the Cisco building takes place on the first floor where there is sufficient shading from surrounding trees and buildings. Additionally, unlike in the Mechanical Workshop, the layer of insulation between the ceiling and roof is properly placed, which provides a more adequate heat barrier.

6.3.1 Infiltration

The audit revealed that the Cisco Building has the same infiltration issues as the Mechanical Workshop: crack spaces underneath the perimeter doors, and louvered windows (Figure 5.6). The specific infiltration values for the rooms in the Cisco building were calculated using the data from the blower door experiments (Table 5.1).

The ACH values in Table 6.1 are produced when the blower door data are extrapolated based on the ELA in each conditioned room. The ACH in Table 6.1 are projections of the present infiltration levels in the Cisco Building. These data were ultimately used as the infiltration parameters for the baseline eQuest model of the building.

Table 6.1: Extrapolated infiltration data for the Cisco Building

Room	Crack Area (ft^2)	Wall Area (ft^2)	Crack Coverage	Window Area (ft^2)	Window Coverage	Window Type	ACH
5.1	0.38	992	0.04%	111	11.2%	Louvered	1.3
5.12	0.75	1642	0.05%	224	13.6%	Louvered	1.6
5.13A	0	869	0%	0	0%	None	0.8
5.13B	0	1115	0%	0	0%	None	0.8
5.14A	0	998	0%	0	0%	None	0.8
5.14B	0	998	0%	0	0%	None	0.8
5.15A	0	1391	0%	0	0%	None	0.8
5.15B	0	1100	0%	0	0%	None	0.8
5.16A	0.19	1043	0.02%	84	8.1%	None	0.8
5.16B	0.19	1043	0.02%	84	8.1%	None	0.8
5.18	0.56	1086	0.05%	189	17.4%	Louvered	2.0
5.19	0.19	1016	0.02%	182	17.9%	Louvered	2.1
5.2[13]	42.0	2160	1.94%	336	15.6%	Louvered	7.5
5.21	0	975	0%	96	9.8%	Louvered	1.3
5.22A	0.56	1320	0.04%	210	15.9%	Louvered	2.2
5.22B	0.19	860	0.02%	54	6.3%	Louvered	0.9
5.22C	0.19	796	0.02%	54	6.8%	Louvered	0.9
5.23B	0	800	0.00%	90	11.3%	Louvered	1.5
5.24	0.94	1466	0.06%	300	20.5%	Louvered	2.8
5.25	0.19	727	0.03%	60	8.3%	Louvered	1.1
5.27A	0.38	891	0.04%	180	20.2%	Louvered	1.8
5.27B	0	919	0.00%	48	5.2%	Louvered	0.8

6.3.2 Lighting

Following the IES method, 750 lux is the illuminance level that will permit the researchers in the metrology labs to effectively accomplish their tasks. The recommended illuminance for the remainder of the rooms is 300 lux, which is a typical illumination level for easy office work and classes. It was not possible to take luxometer

[13] Room 5.2 is unconditioned; occupants leave the exterior doors open for extra airflow.

readings for all rooms in the Cisco building because access could not be obtained to some rooms.

The final readings showed that eleven rooms in the building are over lit and could benefit from a lighting retrofit (Table 6.2). Similar lighting reduction strategies could be applied to both Mechanical Workshop and Cisco buildings. The energy saving lighting alternatives are discussed in APPENDIX D.

Table 6.2: Recommended illuminance levels and lux readings

Room	Recommended Lux per IES Method	Average lux Reading	Status
5.13A	750	723	No Replacement
5.13B	750	536	No Replacement
5.14A	750	543	No Replacement
5.14B	750	569	No Replacement
5.15A	750	553	No Replacement
5.15B	750	686	No Replacement
5.16A	750	494	No Replacement
5.18	300	539	Over Lit
5.20	300	368	Over Lit
5.21	300	385	Over Lit
5.22A	300	495	Over Lit
5.22B	300	396	Over Lit
5.22C	300	235	No Replacement
5.24	300	382	Over Lit
5.25	300	386	Over Lit
5.26	300	391	Over Lit
5.27A	300	375	Over Lit
5.27B	300	375	Over Lit
5.28	300	368	Over Lit

6.3.3 Cooling Equipment

The cooling equipment in the Cisco building is also outdated and inefficient. The average efficiency rating of all the AC units in the building is 9.6 SEER. The first floor Metrology labs would most benefit from a more efficient cooling fleet as the set point is

68 °F when research activities are performed. Interviews with the campus technicians revealed that some of the AC units are over 15 years old and frequent maintenance visits are required to keep the equipment running. The inoperative five-ton AC unit in the education department (room 5.20) exemplifies the unreliable nature of the existing AC equipment. An upgrade to more efficient AC equipment would not only save energy, but would have the added benefit of lowered maintenance costs.

6.3.4 Phantom Loads

The Watts Up Pro power meter was used to find the phantom loads in the Cisco computer labs. The readings showed that each of the 54 computers and monitors in Cisco labs 1, 2, and 3 consume on average 4 W continuous while turned off. The total estimated phantom load for the Cisco building is 432 W, which over the course of one year would waste approximately 3.2 MWh of electricity. These phantom loads can be considered the low hanging fruit for energy efficiency improvements in the Cisco Building. An easy solution is to place the computers and monitors on power strips, which would ensure the devices do not draw an electrical current while turned off. It is important to note that the power strips themselves will not save energy unless the building occupants are educated to turn them off when the loads are not in use. It will therefore be essential to accompany any implementation of power strips with an awareness campaign that teaches building occupants the importance of turning off the power strips when the computers are not in use.

CHAPTER 7 STUDIO BUILDING

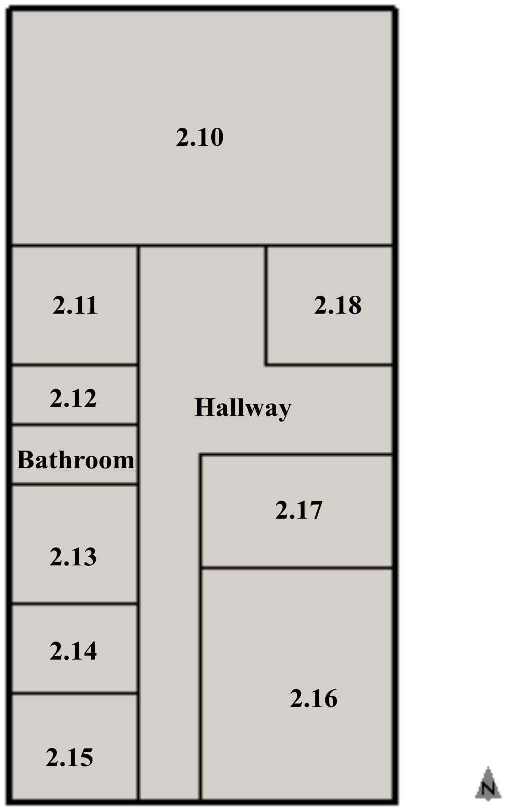
The Studio Building was found to be the fourth largest overall consumer of electricity, and the third largest consumer of electricity on a per square foot basis. In this section, I present an overview of the energy uses and losses in the Studio Building as well as the recommended ECMs per eQuest modeling. The feasibility of each recommended ECM is explained in economics section 9.4.

7.1 Building Description

The Studio Building is a two-story building constructed in 1995 with a gross area of 10,165 ft^2. The performance studio on the north side of the building occupies both floors with an approximate 25 ft. floor to ceiling height. The building serves as the learning headquarters for students in the theater, television, radio, photography, and graphic design departments (Figure 7.2 and Figure 7.3). There are also various administrative offices on the second floor.

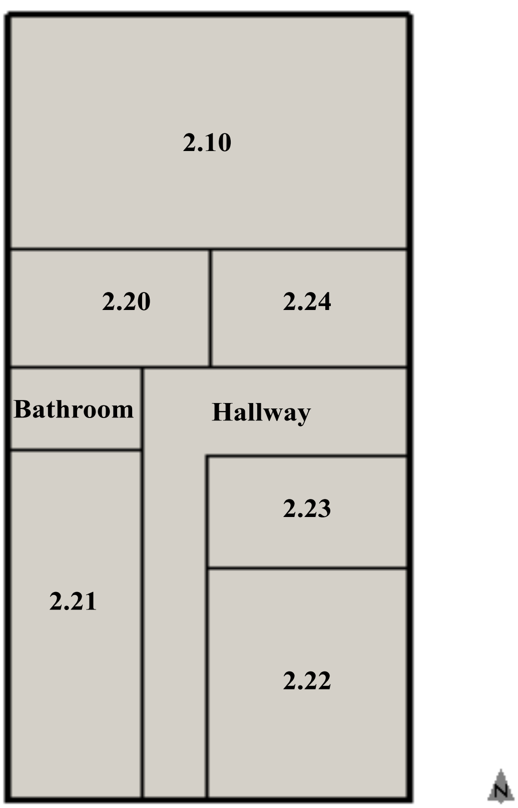
Figure 7.1: Studio Building (facing northwest)

The Studio Building is a very active facility. The first floor has a consistent daily influx of students who come to take care of academic needs at the office of the registrar. The remainder of the rooms in the building have various occupancy schedules: the studios on the first floor are occupied anywhere from 15-25 hours a week, the graphic design and multimedia labs on the second floor have regular class schedules of 25 hours per week, and the administration and faculty offices are typically occupied 40 hours a week (Martinez, 2011). Interviews with professors and temperature data from the datalogger revealed that the setpoints range between 68-72 °F in the rooms on both floors.



Room	Description
2.10	Performance Studio
2.11	Sound Booth
2.12	Registrar
2.13	Production Studio
2.14	Radio 1
2.15	Radio 2
2.16	Lecture Hall
2.17	Photo Lab
2.18	Sound Booth

Figure 7.2: Studio Building first level floor plan



Room	Description
2.10	Performance Studio
2.20	Faculty Offices
2.21	Administration Offices
2.22	Grafic Design Center
2.23	Multimedia Lab
2.24	Computer Lab

Figure 7.3: Studio Building second level floor plan

The building envelope consists of a metal frame and six inches of heavy weight concrete for the exterior and interior walls. The walls in the radio rooms have an extra layer of insulation that is used to minimize sound reverberation and retain cooling. The flooring on the first floor is a concrete slab with vinyl tile on top, and on the second floor the flooring is vinyl tile that is most likely placed on top of lightweight concrete. The roof consists of corrugated metal panels with a medium rust color that are characteristic of all buildings on the UDB campus. In the attic space there is R13 fiberglass insulation placed above the rooms; no insulation is placed above the hallways. All exterior doors are single pane glass with aluminum framing. The windows are user-operable louvered windows that allow for passive cooling when needed (Figure 7.4). Some of these windows have been covered in the graphic design lab and radio production studios in order to mitigate heat gain, reduce daylight and glare for graphic design work, and reduce noise from outdoors during radio show production.

Figure 7.4 Louvered windows (left) and insulation above ceilings (right)

7.2 Energy Uses

Electricity is the only form of energy supplied to the Studio Building. The energy uses in the Studio Building are separated into the same three categories as the Mechanical Workshop: cooling, plug loads (audio control modules, amplifiers, UPSs, and computers), and lighting.

7.2.1 Air Conditioning System

The Studio Building cooling system consists of 11 split type AC units that have a cumulative cooling capacity of 46 tons (Figure 7.5). All units have SEER values of 10 or less. Many of the AC units have been in use for over 10 years and require constant maintenance from the UDB campus technicians. One technician disclosed that typically, at least one of the 11 AC units is repaired every other week (Aleman, 2011).

The Studio Building is unique among the buildings on the UDB campus in that it is the only building equipped with a complete duct system. The existing duct system offers a possibility to consolidate the cooling capacities of the 11 split AC systems into a single, properly sized centrifugal chiller. Additionally, the concurrent high occupancy levels within multiple zones of the building make a central cooling system an attractive option.

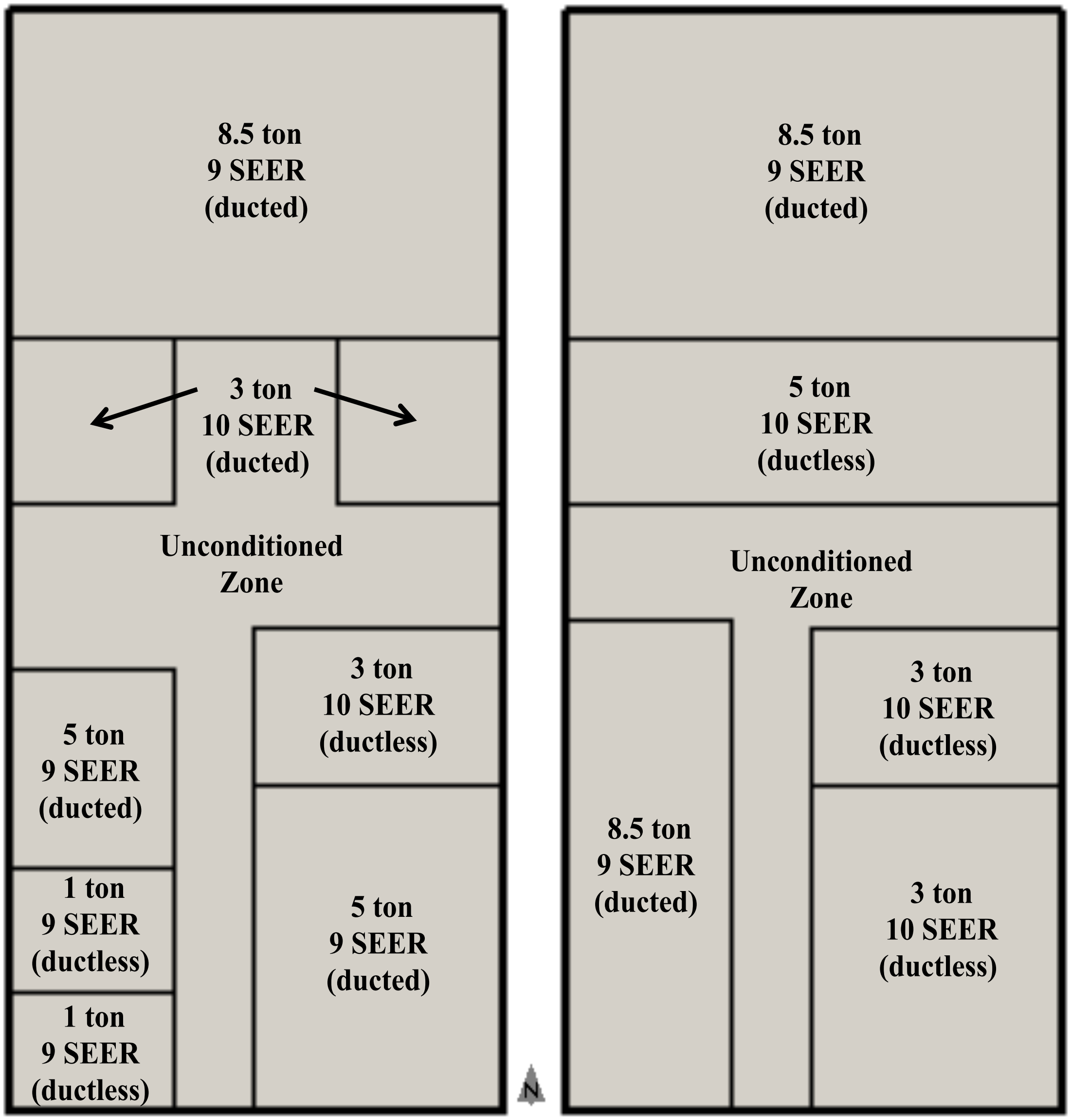


Figure 7.5: First floor (left) and second floor (right) AC zone allocations and specifications

7.2.2 Plug Loads

The estimated equipment power density on the first floor is 1.7 W/ft^2 (the total area of the first floor is 5,083 ft^2). The most energy intensive loads are the computers and studio production equipment (amplifiers, mixers, and other various audio control devices). The production equipment alone accounts for 67% (1.1 W/ ft^2) of the total equipment load on the first floor. Unfortunately, the production equipment has non-elastic usage demands and therefore its energy consumption cannot be reduced.

The power density of the second floor is 2.9 W/ft^2. The most significant plug loads on the second floor are the 85 computers in the graphic design, multimedia, and Macintosh™ computer labs that are used 20-25 hours a week during classes. There are also 10 faculty and staff computers that are used 40 hours a week.

7.2.3 Lighting System

The majority of the lights in the Mechanical Workshop Building are 32 W T8 fluorescent tubes, but some rooms are equipped with additional lighting fixtures. The photography studio has an additional 800 W of high quality studio lights, which results in a lighting power density of 4.8W/ft^2 for the 360 ft^2 space. The performance studio has an additional four 250 W metal halide bulbs, which results in a lighting power density of 1.7 W/ft^2 for the 1,520 ft^2 space. The total lighting power density on the first floor is 1.3 W/ft^2 and 0.65 W/ft^2 on the second floor.

The illuminance measurements were taken in early June, on a sunny day with minimal cloud cover; see APPENDIX D for a complete listing of measurements. The lighting intensities are the highest in the second floor faculty offices (544 lux) and Lecture Hall 2.16 (468 lux) due to the excellent daylight resource within the rooms. The lowest lighting intensities were found in the radio studios (151 lux), as the UDB disc jockeys prefer working in a sparsely lit space. The average lighting intensity of all rooms in the building is 350 lux. The lamp fixtures have plastic covers over them, which create more diffuse light and decrease the illuminance in the room.

7.3 Energy Losses and Audit Highlights

The walkthrough audits and detailed building study revealed that there are four causes of energy waste in the Studio Building: (1) leaks in the louvered windows and interior doors connecting unconditioned and conditioned spaces, (2) heat gain through the roof, (3) out-of-date cooling equipment, and (4) phantom loads in the computer labs.

7.3.1 Building Leaks

The building audit revealed that there are leaks in the building that contribute to loss of conditioned air. The two most obvious air escapes are: (1) the louvered windows (Figure 7.6), and (2) the cracks around hallway doors (Figure 7.7). Unfortunately, there were no suitable rooms in the Studio Building where a blower door test could be used to empirically estimate the amount of infiltration from these leaks.

Figure 7.6: Example of leaks in louvered windows (Multimedia Lab)

Some of the louvered windows have a tighter seal than others. The window in Figure 7.6 is shut yet still has an obvious leak. The window shown is the worst-case scenario found in the building.

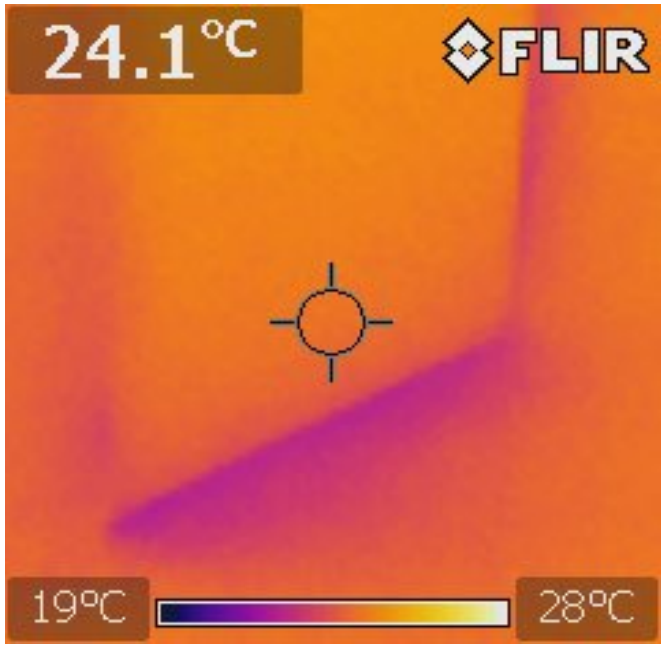


Figure 7.7: Infrared image of cool air leaking from the bottom of the Radio Production Studio into the warm hallway

The upward sloped diagonal blue line in Figure 7.7 is conditioned air exfiltrating the Radio Production Studio into the unconditioned hallway. All conditioned rooms in the Studio Building are connected to the unconditioned hallway. None of the doors are currently equipped with weather stripping to prevent the loss of conditioned air. A reasonable infiltration rate of 1.8 ACH was assumed for all rooms in Studio Building after iterative calibrations of the eQuest baseline model.

During the building walkthrough I found additional leaks in the building that weren't due to faulty building design, but inappropriate user behavior. Figure 7.8 is an instance of a window being left wide open while the AC was on. It is uncertain how often this type of behavior takes place, but it is likely that it occurs in other buildings on campus. Energy efficient equipment and retrofits can be useless if user behavior is not aligned with energy savings goals. UDB should initiate energy awareness campaigns to increase the knowledge of the importance of energy conservation in their buildings.

Figure 7.8: Window left open during the operation of AC in the Multimedia Lab

7.3.2 Heat Gain

The infrared photography of the Studio Building showed that the attic space is subjected to intense amounts of heat gain during the day (Figure 7.9).

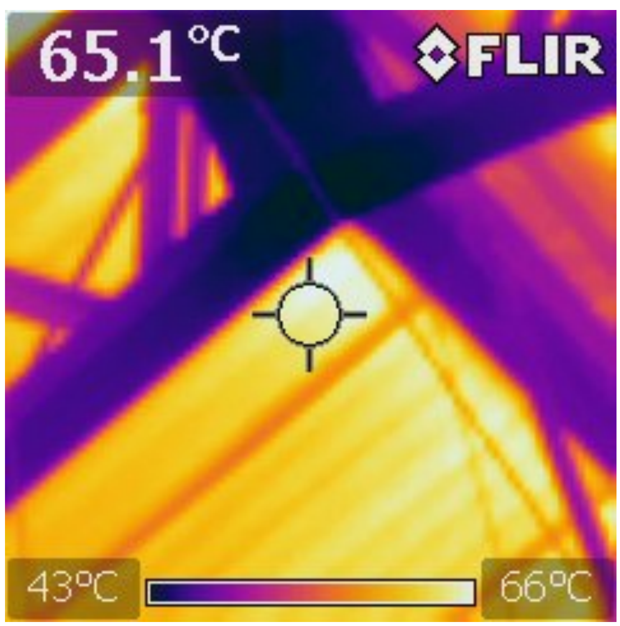


Figure 7.9: Infrared image of the Studio Building roof (taken from inside the attic)

The photo in Figure 7.9 was taken at 1:15 PM on June 28th; the outside air temperature during that time was recorded as 92 °F. The warmest temperature on the roof is approximately 65 °C, or 149 °F, which is 57 °F hotter than the outside air. This large amount of radiant heat gain demonstrates the need for implementing either a heat barrier or improved ventilation within the attic space of the Studio Building.

7.3.3 Cooling Equipment

The cooling equipment in the Studio Building is out dated and inefficient. Some of the AC units were installed when the building was built in 1995. Many of the units require consistent maintenance and repairs (Figure 7.10). There are two 8.5 ton 9 SEER units that have been out of service for over a year. Similar to the Mechanical Workshop and Cisco Building, the Studio Building can benefit from an upgrade to new cooling equipment. A retrofit to the cooling system would save both energy and money in avoided maintenance costs.

Figure 7.10: Repairs to one of the 3-ton AC units in the Studio Building

7.3.4 Phantom Loads

Power meter measurements showed two sources of phantom loads in the Studio Building: (1) computers, and (2) UPSs. Using the Watts Up Pro power meter I found 60 computers and seven UPSs in the radio production, multimedia lab, and computer lab that draw a small amount of electrical current while turned off. The total phantom load found in the Studio Building was 342 W, which over the course of a year wastes approximately 2.5 MWh of electricity. A power strip is a simple way of preventing these loads from drawing an electric current while turned off. It is important to note that the power strips themselves will not save energy unless the building occupants are educated to turn them off when the loads are not in use. It will be important to accompany any implementation of power strips with an awareness campaign that teaches building occupants the importance of turning off the power strips when the computers are not in use.

CHAPTER 8 EQUEST MODELING AND RETROFIT ALTERNATIVES

The data collected during the audits (i.e. building materials, equipment specifications, readings from auditing instruments/tools, and information gathered from building occupants and technicians) were used to create eQuest models of the Mechanical Workshop, Cisco Building, and Studio Building. This chapter presents the potential energy savings of the various retrofit alternatives modeled in eQuest. Combinations of the retrofits presented in this chapter were tested to observe how the retrofits interact with each other. The long-term feasibility of each retrofit is discussed in the Economics chapter.

8.1 Model Calibration

Several calibration iterations were carried out for each model based on changes to occupancy schedules, cooling setpoints, and infiltration rates for the zones where sufficient data were not available. The monthly outputs of each baseline model are within a ±10% margin of error when compared to the actual utility bills unless otherwise stated.

8.1.1 Mechanical Workshop and Cisco Building

As previously mentioned, the same electric sub-meter monitors the energy use of the Mechanical Workshop and Cisco Building. Because the Mechanical Workshop has no individualized energy records to compare with the eQuest model outputs, the records from the grouped electric sub-meter were used to calibrate both the Mechanical

Workshop and Cisco Building models (Figure 8.1). The energy outputs from the two building models were added and compared to the actual electric sub-meter (Figure 8.2).

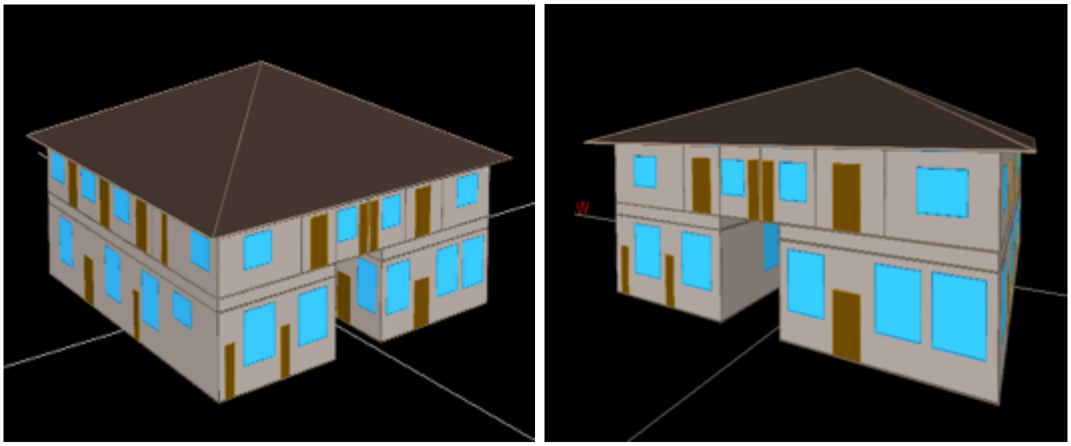


Figure 8.1: Visual renderings of eQuest models of the Mechanical Workshop Building (left) and Cisco Building (right)

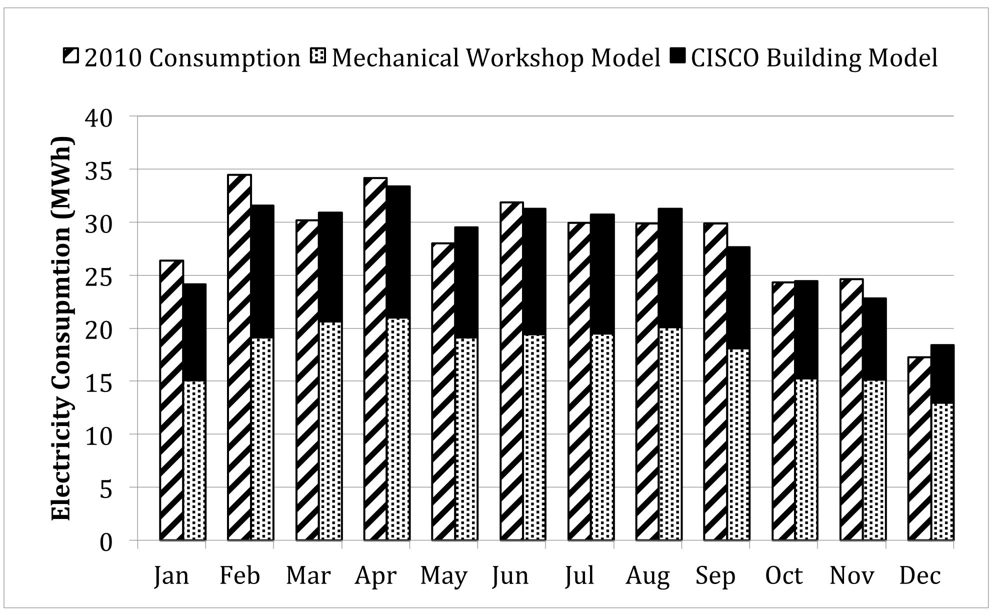


Figure 8.2: Comparison of 2010 electricity consumption and model outputs.

8.1.2 Studio Building

The Studio Building shares a sub-meter with two other buildings, the Biomedical Building and Electronics Building 4. The individualized energy consumption of each building was estimated by means of walk through audits that were explained in the

Methods section. The resulting information was used to calibrate the baseline eQuest model (Figure 8.4).

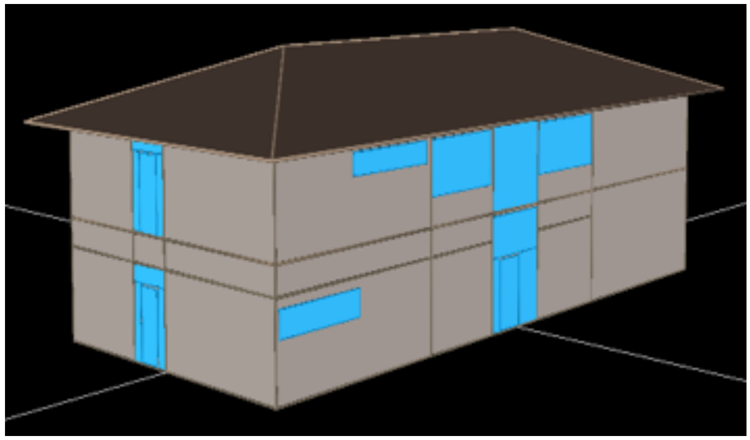


Figure 8.3: eQuest model of the Studio Building

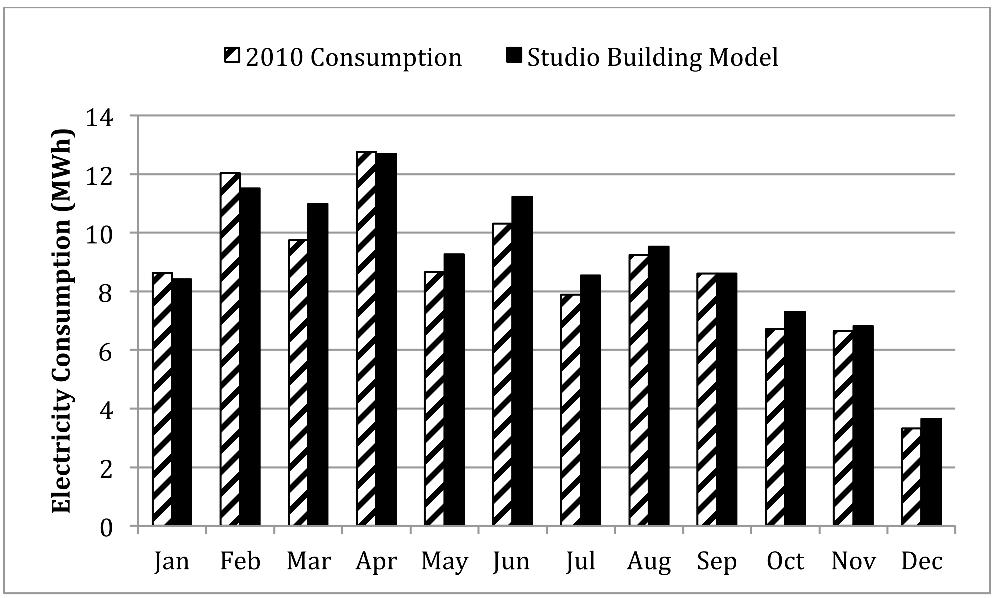


Figure 8.4: Comparison of 2010 electricity consumption and Studio Building model output. The 2010 consumption is 66% of the monthly consumption recorded by the sub-meter that records the electricity used by the Biomedical Building, Electronics Building 4, and the Studio Building (See Chapter 4 for details).

Although the model estimate for March is 12.6% higher than the actual energy consumption, the model is considered representative of the real building even though this month does not fall within a ±10% margin of error. The difference is most likely due to discrepancies between the eQuest weather file and anomalous weather patterns for March

2010. Numerous iterations were carried out to find a reasonable infiltration rate. The final air infiltration rate was assumed to be 1.8 ACH for all conditioned zones as this rate created the most accurate energy output.

8.2 Overview of the ECMs for the Mechanical Workshop and Cisco Building

Because the Mechanical Workshop and Cisco Building have similar architectural designs and energy losses, the ECMs for the two buildings are presented together. Five potential retrofits were analyzed for both buildings: (1) implementation of cool roofs, (2) reduction of outside air infiltration, (3) an upgrade to SEER 13 cooling equipment, (4) an upgrade to SEER 16 cooling equipment, and (5) implementation of attic fans.

The baseline Mechanical Workshop model revealed that the energy used is broken down by the following percentages: 53% air conditioning, 40% equipment, and 7% lighting. The energy breakdown for the Cisco building is: 71% air conditioning, 19% equipment, and 10% lighting (Figure 8.5).

There is more energy dedicated to equipment use in the Mechanical Workshop due to the heavy machinery on the first floor. The retrofit alternatives focus on minimizing AC consumption, as it is the dominant load in both buildings. Additionally, given the low SEER ratings, the AC systems also have the most savings potential in comparison to other loads within the buildings (i.e. plug loads which are predominantly inelastic and the lighting which is reasonably efficient).

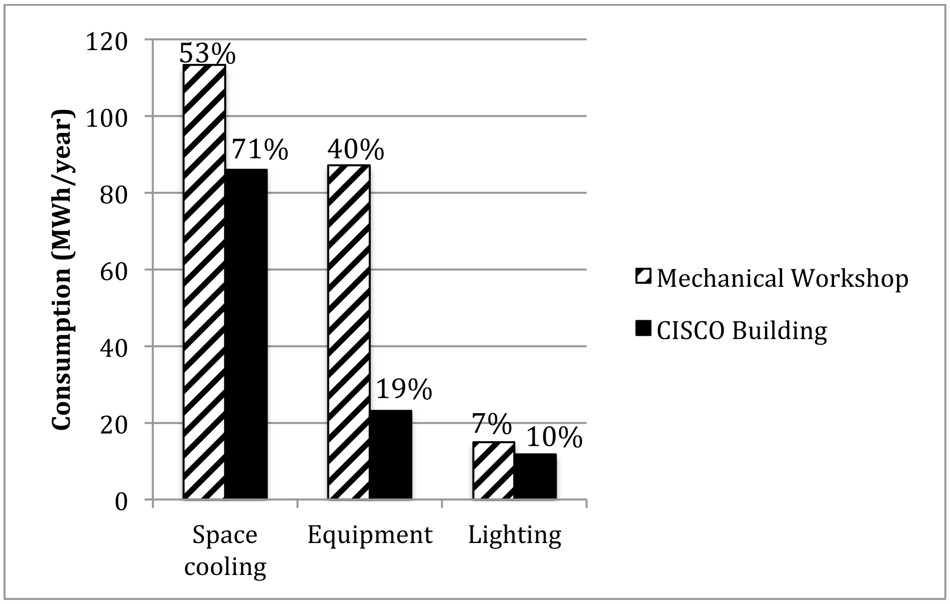


Figure 8.5: Distribution of energy use in the Mechanical Workshop and Cisco Building

An overview of the potential energy savings as predicted by the eQuest modeled retrofits are given in Table 8.1 for the Mechanical Workshop. A summary of the same retrofits modeled for the Cisco Building is given in Table 8.2. For initial investment costs as well as materials descriptions of the retrofits in the Mechanical Workshop see APPENDIX E; for the Cisco Building see APPENDIX F. The results for both buildings show that the most energy can be saved with upgrades to SEER 13 or SEER 16 cooling equipment. The cool roof and infiltration-reducing retrofits are less costly investments and are also viable energy saving options. The attic fan retrofit in the Cisco Building does not receive significant return because the energy consumed from the fans almost offsets the anticipated energy savings.

Table 8.1: Summary of the Mechanical Workshop Building retrofit alternatives

Alternative	Consumption (MWh/year)	Savings (MWh/year)	Reduction in Total Energy Consumption	Reduction in AC Energy Consumption
Baseline	213.5	-	-	-
Less Infiltration	211.4	2.1	1.0%	1.9%
Attic Fans	210.6	2.9	1.4%	2.6%
Cool Roof	207.9	5.6	2.6%	4.9%
SEER 13	184.5	29.0	13.6%	25.6%
SEER 16	174.3	39.2	18.4%	34.6%

Table 8.2: Summary of the Cisco Building retrofit alternatives

Alternative	Consumption (MWh/year)	Savings (MWh/year)	Reduction in Total Energy Consumption	Reduction in AC Energy Consumption
Baseline	121.9	-	-	-
Attic Fans	121.4	0.5	0.4%	0.6%
Cool Roof	118.6	3.3	2.7%	3.8%
Less Infiltration	118.5	3.4	2.8%	3.9%
SEER 13	99.5	22.4	18.4%	25.9%
SEER 16	81.9	40.0	32.8%	46.2%

Through eQuest modeling, I found that the Cisco Building's average cooling load due to heat gain and infiltration is 110 MBtu/month, and in the Mechanical Workshop the cooling load due to heat gain through the roof and infiltration is 183 MBtu/month. If the cool roof and reduced infiltration retrofits are implemented together, these cooling loads can be reduced by 52 MBtu/month in the Cisco Building and 68 MBtu/month in the Mechanical Workshop. Reducing the cooling load has two advantages: (1) lower energy consumption and (2) more comfortable rooms for the building occupants.

The eQuest report *SS-O: Space Temperature Summary* showed that in the baseline models, there are a number of hours during the year where the AC units are on but are unable to meet an occupant specified setpoint. To demonstrate the effect that a cool roof and a reduced infiltration retrofit would have on comfort, I sorted the data of the SS-O report into two categories: (1) unmet hours, when the AC is on but the zone temperature is 75 °F or greater, and (2) met hours, when the AC is on and the zone is cooled to a temperature lower than 75 °F. A summary of the annual temperatures in all 16 zones of the Cisco Building is shown in Figure 8.6. Figure 8.7 shows a summary of the annual temperatures in all 13 zones of the Mechanical Workshop.

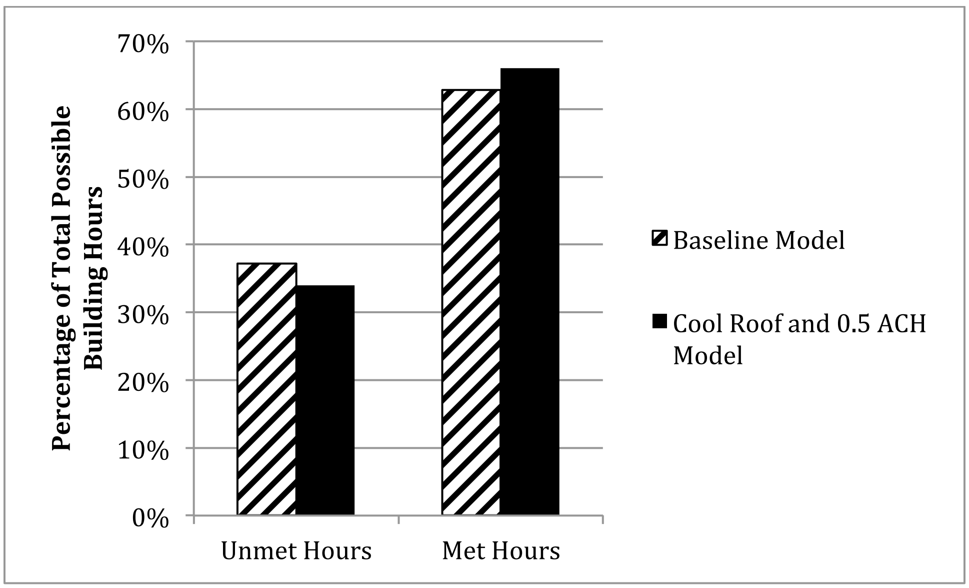


Figure 8.6: Comparison of modeled annual zone temperatures for the Cisco Building

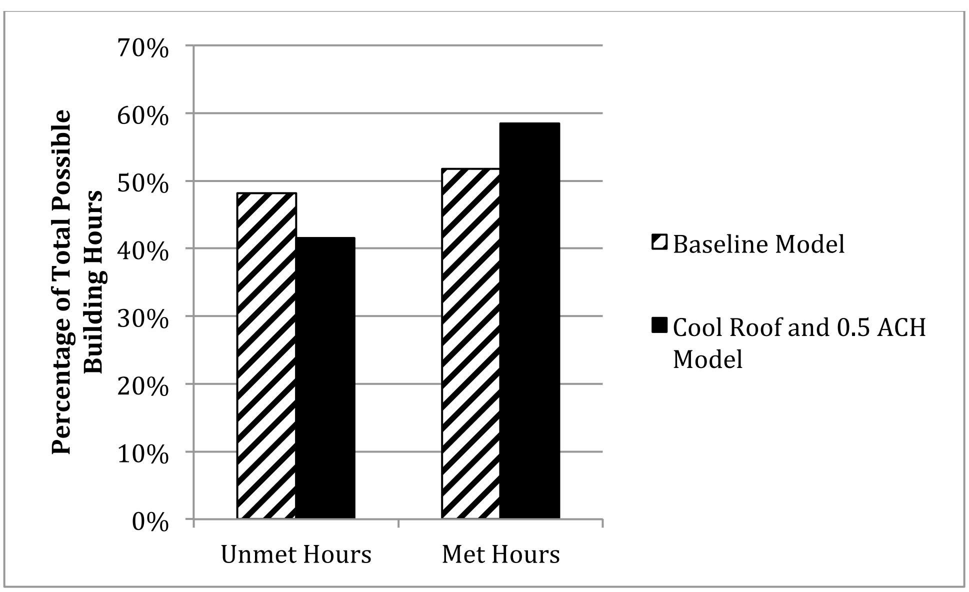


Figure 8.7: Comparison of modeled annual zone temperatures for the Mechanical Workshop

Both Figure 8.6 and Figure 8.7 show that a cool roof and reduced infiltration retrofit will increase the number of met hours. In other words, there will be more hours during the year when the AC units are able to cool the zones to 75 °F or less. It is estimated that addressing the heat gains and infiltration problems in the Cisco Building will result in 1,200 more met hours a year. In other words, over the course of one year, the 16 conditioned zones in the Cisco Building will collectively experience an additional 1,200 operation hours out of the year where the setpoint is met. In the Mechanical Workshop, the same retrofit will result in approximately 3,500 more met hours a year for the 13 conditioned zones of the building.

The cool roof and reduced infiltration retrofits are not only a great opportunity to improve the comfort levels of the building occupants, but they also can be used to reduce the cooling load before upgrading to higher SEER cooling equipment. When improving building performance, it is important to fix the building envelope problems before installing new HVAC equipment. Addressing the building envelope issues first and accurately modeling the savings will ensure that the new HVAC equipment is more appropriately sized.

8.2.1 Cool Roof

To alleviate the heat gain through the roof and attic in the Mechanical Workshop and Cisco Building, the eQuest models were simulated with added cool roof constructions, which are inclusive of the radiant barrier. The cool roof retrofits are estimated to reduce the same amount of heat gain in both the Mechanical Workshop and Cisco Building (Figure 8.8). The similarity is not surprising as the construction and layouts of the two buildings are nearly identical.

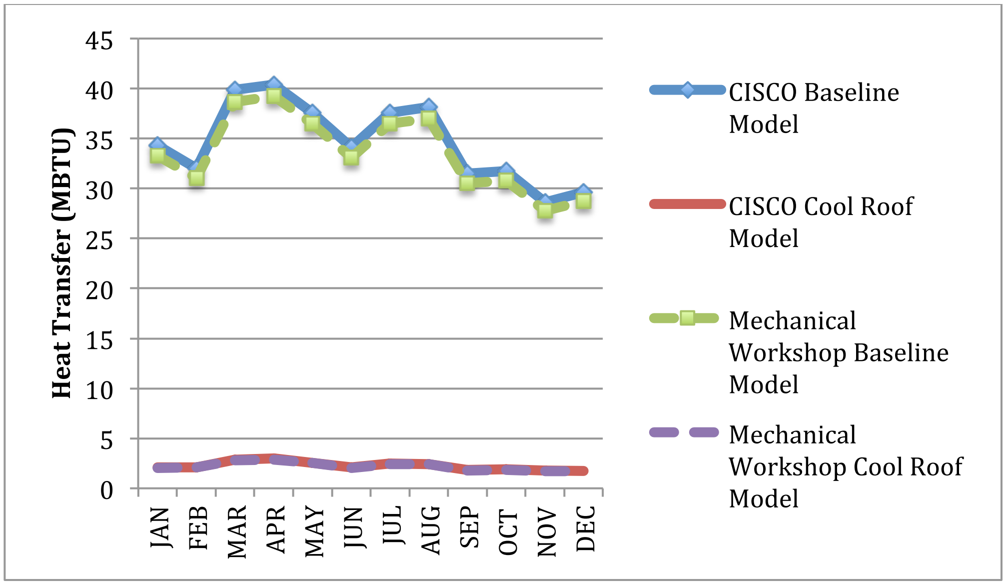


Figure 8.8: Comparison of heat transfer into attic space with and without cool roof

Figure 8.8 was produced using the eQuest output report *LS-E: Space Monthly Load Components*. The report shows that 31 MBtu/month is the average cooling load reduction that results from the cool roof retrofit. Decreasing the heat gain through the roof will not only save energy, but will also provide cooler, more comfortable conditions for the building occupants.

If the cool roof is implemented in the Mechanical Workshop there is potential to save 5.5 MWh/year, which would decrease the cooling demand by 4.9%. The same retrofit in the Cisco Building would save 3.3 MWh/year and reduce cooling demand by 3.8%. The savings are higher for the Mechanical Workshop because all the AC units are installed on the second floor, whereas the majority of the cooling capacity in the Cisco building is installed on the first floor where there is adequate shade from surrounding buildings and vegetation.

8.2.2 Less Infiltration in Conditioned Spaces

The results presented in sections 5.3.1 and 6.3.1 show that the rooms in the Mechanical Workshop and Cisco buildings are highly permeable and are in need of air sealing. To model this retrofit the eQuest infiltration parameters were reduced to 0.5 ACH in all conditioned rooms of the buildings. It is assumed that 0.5 ACH can be achieved by installing weather stripping below perimeter doors, fixing broken ceiling panels, and replacing the louvered windows in conditioned rooms with sealed windows.

The eQuest report *LS-F: Building Monthly Load Components* describes the entire building's monthly cooling load due to infiltration. The outputs from the report for both baseline models and both retrofit models are displayed in Figure 8.9. Compared to the baseline models, a reduced infiltration rate will decrease the cooling load by 27 MBtu/month in the Mechanical Workshop and 16 MBtu/month in the Cisco Building.

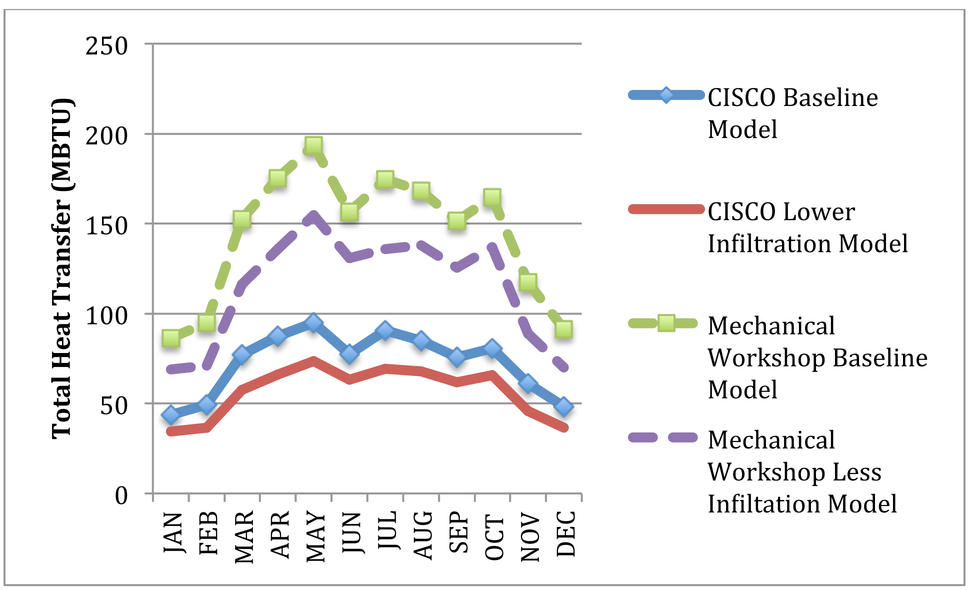


Figure 8.9: Comparison of building cooling loads due to infiltration

The eQuest model indicates that this retrofit could save 2.1 MWh/year in the Mechanical Workshop, which would offset 1.9% of the current AC demand. The same retrofit in the Cisco building would save 3.4 MWh/year thereby reducing the AC demand by 3.9%. The feasibility of installing this retrofit is explained in APPENDIX E for the Mechanical Workshop and in APPENDIX F for the Cisco Building.

8.2.3 More Efficient Cooling Equipment

Some of the AC units installed in the Mechanical Workshop and Cisco buildings are more than 15 years old (Aleman, 2011), and all of the AC units are very inefficient by today's standards. A cooling equipment retrofit was simulated in eQuest by increasing the condenser coefficient of performance (COP) of all AC units. This retrofit assumes that all the upgraded AC units will have the same cooling capacities and usage schedules as the previous AC units.

Two alternatives for improved cooling equipment were modeled, one for SEER 13 and the other for SEER 16. The new systems would utilize refrigerant 410A (R-410A) instead of R-22, which is currently used in all of UDB's AC systems. According to the EPA, R-410A is an acceptable substitute for R-22 as it does not contribute to depletion of the ozone layer, but like R-22, does contribute to global warming (EPA, 2010a). The 100-year GWPs of R-22 and R-410a are 1,810 CO_2e and 2,090 CO_2e, respectively (IPCC, 2007). Essentially, if the R-410A were to leak or be released into the atmosphere, it would act as a GHG in a similar way as the existing R-22. However, since the R-410A will be used in more efficient cooling equipment (i.e. higher SEER) it will reduce UDB's GHG emissions due to a reduction in electric power consumption.

8.2.3.1 Upgrade to SEER 13

The expected savings from an upgrade to SEER 13 in the Mechanical Workshop are 29.0 MWh/year, which equates to a 25.6% decrease in cooling consumption. The

Cisco building would achieve 22.4 MWh/year in savings, which results in a 25.9% reduction in cooling consumption.

8.2.3.2 Upgrade to SEER 16

The projected savings of the SEER 16 retrofit are the highest of the retrofits. A complete upgrade to SEER 16 cooling equipment in the Mechanical Workshop results in an annual savings of 39.2 MWh and a 34.6% reduction in the current cooling demand. The same upgrade in the Cisco building would save 40.0 MWh/year, and reduce cooling consumption by 46.2%.

There may be obstacles to procuring SEER 16 cooling equipment in El Salvador. Many of the AC suppliers I spoke with in El Salvador noted that the current demand for SEER 16 equipment is small and therefore the availability of SEER 16 is limited.

8.2.4 Attic Fans

An alternative strategy to cool roofs is the use of attic fans, which increases the air circulation in the attic space thereby reducing the amount of heat transferred from the roof into the building. This retrofit was modeled in eQuest by increasing the air infiltration in the attic to the maximum rate of 10 ACH. In the Mechanical Workshop, the retrofit results in 2.9 MWh/year of energy savings and in the Cisco Building the retrofit yields 0.5 MWh/year in energy savings.

There are two reasons why the attic fan retrofit saves less energy than the cool roof: the air circulated in the attic may not be sufficiently cool to slow the heat transfer from the roof (i.e. the outside air drawn into the attic will be the hottest when cooling is needed in the building). Also, the electric energy consumed by the electric fan offsets some of the energy savings.

8.3 Overview of the ECMs for the Studio Building

The Studio Building has a distinction among the buildings on the UDB campus in that it has an extensive duct network that runs through four conditioned zones in the building: the administration offices, performance studio, production studio, and first floor lecture hall. The duct network is currently connected to six split AC systems, but the network could possibly be used to distribute air from a centralized cooling system instead.

I modeled two possible central systems in eQuest: the first is a 15-ton system that would sufficiently condition the four zones that are currently connected to the duct network. The 15-ton system is supplemented by five upgraded SEER 13 split systems to serve the zones that are not connected to the duct network. The second system I modeled is a 30-ton system that would effectively serve all the zones that are currently conditioned. The 30-ton system has an additional cost of installing ducts in the zones that currently do not have them. Additionally, the same retrofits that were modeled for the Mechanical Workshop and the Cisco Building were modeled for the Studio Building.

The baseline model revealed that the total energy used in the Studio Building is broken down into the following percentages: 70% space cooling, 22% equipment, and 8% lighting. These figures are based on the manufacturer specifications for AC units and other building equipment, as well as the scheduling information collected during the building audit. An overview of the potential energy savings as predicted by the eQuest modeled retrofits is shown in Table 8.3. For initial investment costs as well as materials descriptions of the retrofits see APPENDIX G.

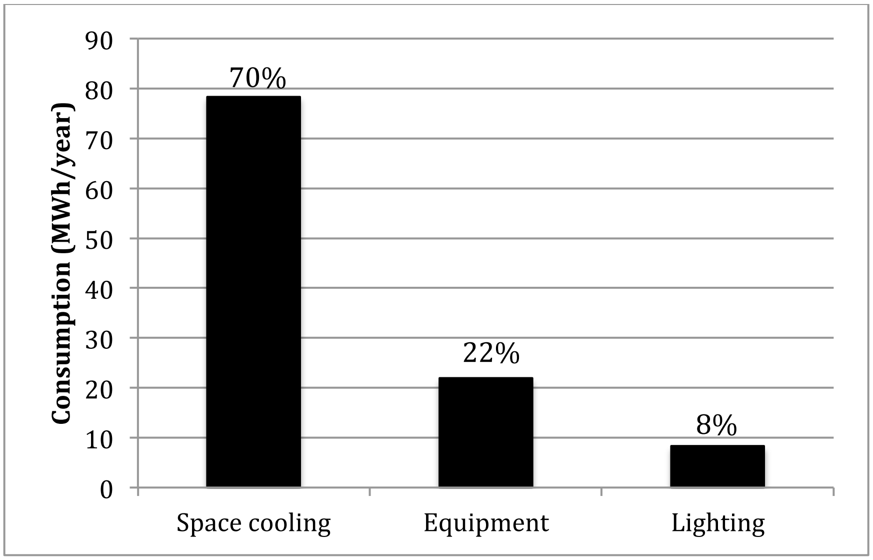


Figure 8.10: Studio Building energy distribution

Table 8.3: Summary of retrofit alternatives for the Studio Building

Alternative	Consumption (MWh/year)	Savings (MWh/year)	Reduction in Total Energy Consumption	Reduction in AC Energy Consumption
Baseline	108.7	-	-	-
Cool Roof	107.6	1.1	1.0%	1.3%
Less Infiltration	104.7	4.0	3.7%	5.1%
SEER 13	95.5	13.2	12.1%	16.8%
30-ton Central Cooling System	94.5	14.2	13.0%	18.1%
15-ton Cooling System w/ Supplemental Split Units	89.8	18.8	17.3%	24.0%

The eQuest model showed that 93 MBtu/month is the average cooling load the building incurs from heat gain through the roof and from infiltration. This cooling load would be reduced by approximately 34 MBtu/month if the cool roof and infiltration retrofit were implemented together. Figure 8.11 is used to demonstrate the effect these retrofits would have on comfort levels within the building. The figure shows that currently, the temperatures within the 11 conditioned zones are 75 °F or higher 21% of the time (i.e. 4,200 collective unmet hours across all 11 conditioned zones per year). It is expected that the 11 conditioned zones of the building will collectively experience an additional 1,650 met hours each year (an 8% increase) if the cool roof and reduced infiltration retrofits is implemented.

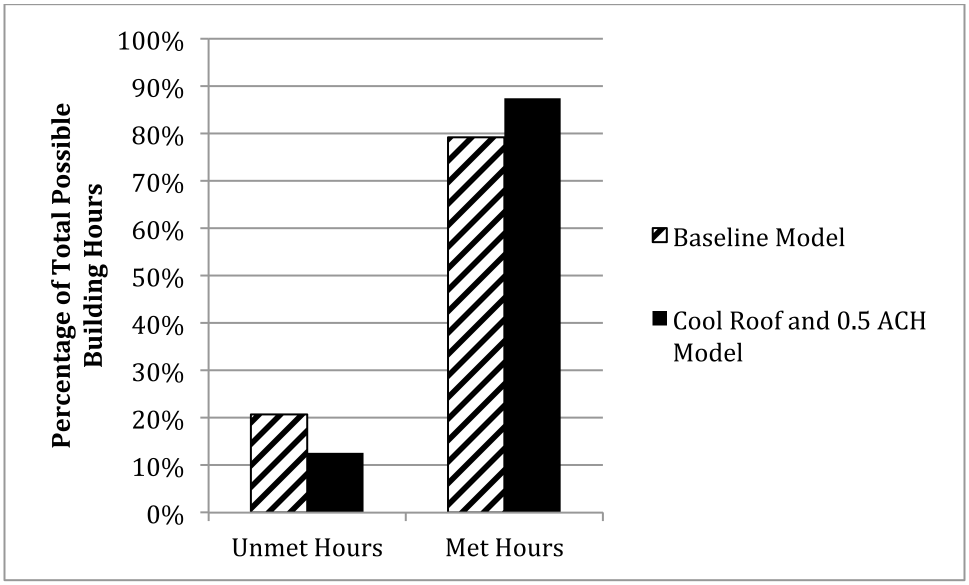


Figure 8.11: Comparison of modeled annual zone temperatures for the Studio Building

8.3.1 Cool Roof

To alleviate the heat gain through the roof and attic in the Studio Building, the eQuest model was also simulated with a cool roof construction. The cool roof for the Studio Building was modeled with the same approach as the cool roofs modeled for the Mechanical Workshop and Cisco Building (Section 8.2.1).

The eQuest report *LS-E: Space Monthly Load Components* showed that 17 MBtu/month is the average cooling load reduction that results from the cool roof retrofit (Figure 8.12).

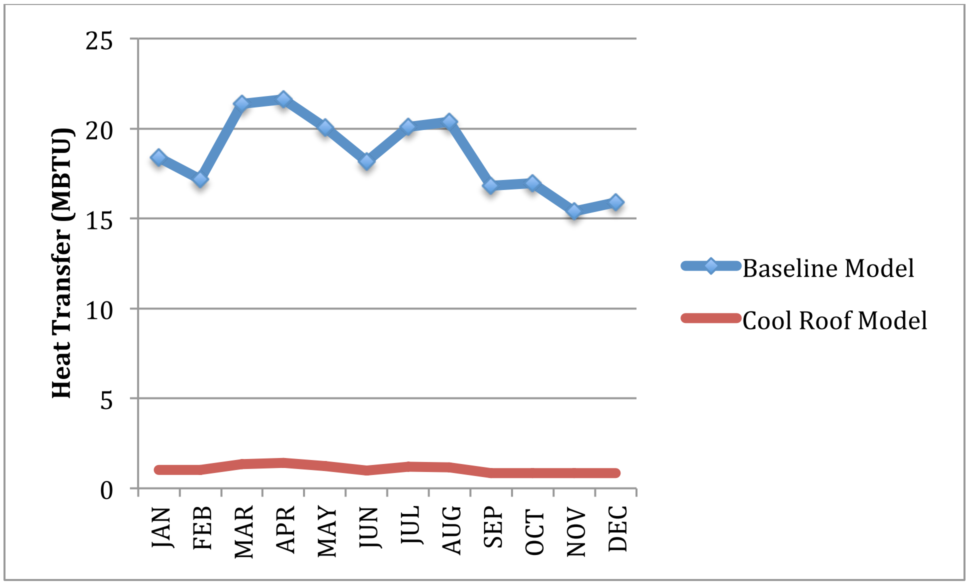


Figure 8.12: Comparison of heat transfer into the Studio Building attic with and without a cool roof

The eQuest energy output showed that the cool roof retrofit has the potential to save 1 MWh/year of electricity, which would decrease the building's cooling demand by 1.3%.

8.3.2 Less ACH in Conditioned Spaces

Section 7.3.1 showed multiple points of infiltration and exfiltration within the conditioned rooms of the Studio Building. It is assumed that UDB can reduce the infiltration rate to 0.5 ACH in these spaces by installing weather stripping below hallway doors and replacing the louvered windows. The eQuest model indicates that this retrofit will save approximately 4 MWh/year and reduce the building's cooling demand by 5.1%.

The eQuest report *LS-F: Building Monthly Load Components* shows that currently, 75 MBtu/month is the Studio Building's average cooling load due to infiltration. This load can be lowered to an average of 58 MBtu/month if the infiltration into the Studio Building rooms is reduced to 0.5 ACH (Figure 8.13)

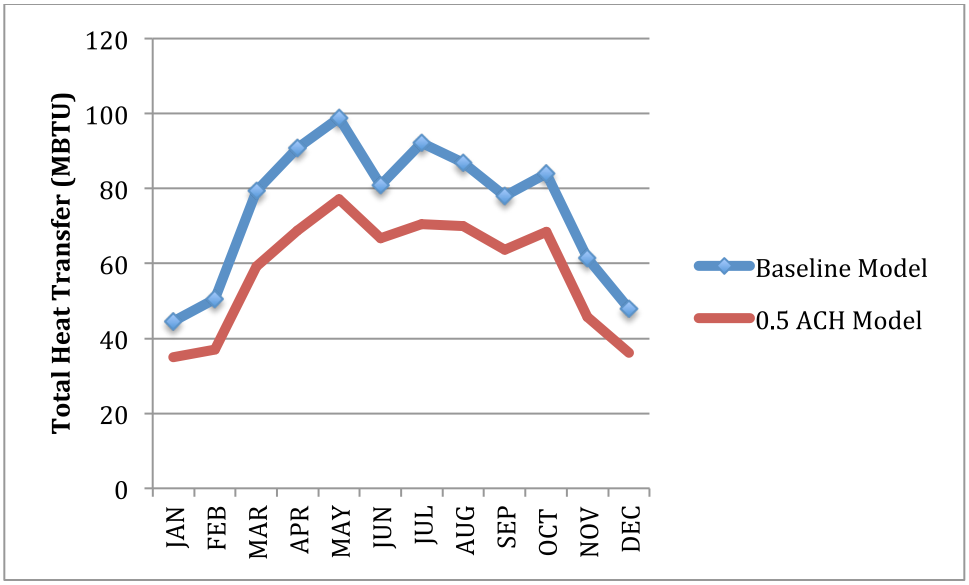


Figure 8.13: Comparison of the Studio Building's cooling load due to infiltration

8.3.3 Upgrade to SEER 13

Because the cooling equipment in the Studio Building is out dated and inefficient, the building model was tested with an upgrade to SEER 13 cooling equipment. The eQuest model output shows that upgrading all 11 existing AC units to SEER 13 saves approximately 13.2 MWh/year and reduces the cooling demand by 16.8%.

8.3.4 15-ton Central Cooling System with Supplemental Split Systems

This retrofit involves connecting a 15-ton, 13 SEER chiller to the existing ductwork connected to the administration offices, performance studio, production studio, and first floor lecture hall. The 15-ton chiller was sized using the eQuest output report *LS-A: Peak Cooling Load*, which provides monthly peak cooling loads for all zones in the building. The retrofit also accounts for SEER 13 upgrades for the zones not connected to the duct network, which include: the sound booth, photo lab, graphic design lab, multimedia lab, computer lab, and faculty offices. According to the eQuest results, this retrofit is predicted to save 18.8 MWh/year in energy bills and lower the cooling demand by 24.0%.

8.3.5 30-ton Central Cooling System

This retrofit was performed in eQuest by connecting all conditioned zones to one 30-ton, 13 SEER centralized chiller. The chiller capacity was sized by summing the annual peak cooling loads for all zones as specified by the eQuest LS-A report. It is estimated that a centralized cooling system would save the Studio Building 14.2 MWh/year in energy and reduce the cooling demand by 18.1%.

CHAPTER 9 ECONOMICS

This chapter presents the economic analyses that are used to assess the costs and benefits of the suggested retrofits for the three buildings audited in this project. Combinations of the aforementioned retrofits were run in eQuest to see how the retrofits interact with each other. The analyses were performed for a 20-year period and account for the initial investment, long-term savings, and repair costs related to each ECM. The Net Present Value (NPV) and payback period are used to compare the different alternatives. The retrofits recommended in this chapter have a range of initial investments so as to provide UDB with various options and levels of financial commitment. In all options except for the Cisco Building lighting retrofit, the NPV is a factor of the initial investment, where a higher initial investment equals a higher NPV.

Because the future price of electricity is a source of uncertainty within the economic analyses, a sensitivity analysis is presented to show how varying future electricity prices can affect the NPV and payback periods of each retrofit. The annual electricity cost escalation rates chosen for the sensitivity analysis are 0%, 3%, 6%, and 9%, where 3% represents the base case scenario presented in sections 9.2 through 9.4.

9.1 Key Economic Assumptions

For this analysis, I used a price of electricity of $0.15/kWh, which is based on UDB's 2010 energy bill records.[14] From 2005 to 2011, the average price of electricity in El Salvador increased by 8.9 percent per year on top of inflation (SIGET, 2011). This

[14] The actual price of electricity that UDB pays is more complex and dependent on hourly demand charges. However, I found that the average price UDB paid for electricity over the course of 2010 was $0.15/kWh.

escalation rate is unlikely to continue into the far future and the analysis therefore assumes a more conservative baseline rate of 3%. Sonia Bermudez of the UDB Economics department calculated that UDB's discount rate would be on the order of 8% for these potential projects. The materials and labor costs were obtained from various suppliers within the department of San Salvador. Finally, it is assumed the salvage value offsets the disposal costs (i.e. there is no net salvage value).

9.2 Economic Evaluation of ECMs for the Mechanical Workshop

Analyses for a total of 14 retrofit scenarios were performed for the Mechanical Workshop. Descriptions of the materials, installation costs, and projected savings for each retrofit are given in APPENDIX E. From the analysis, it was found that the three most lucrative retrofits are the cool roof, the SEER 13 upgrade, and the SEER 13 upgrade in conjunction with reduced infiltration rates (Table 9.1). These retrofits were selected based on their quick payback periods and the NPV; the year-by-year cash flow analyses for these retrofits can be viewed in APPENDIX K. The procedures for implementing the lighting retrofit are outlined in APPENDIX D.

Table 9.1: Overview of the most economically promising retrofits for the Mechanical Workshop

Retrofit and Option No.	Initial Investment	Energy Savings (kWh/yr)	First Year Savings ($)	NPV ($)	Payback (years)	GHG abatement (tCO_2e/yr)
Cool Roof (1)	$4,717	5,540	$831	$4,639	7.7	3.3
SEER 13 Upgrade (2)	$24,505	28,950	$4,343	$20,680	7.0	17.2
Less Infiltration and SEER 13 (3)	$28,647	31,230	$4,685	$28,739	7.7	18.6

The individual energy savings presented in Table 9.1 are generally proportional to the respective retrofit's initial investment. Option 1 has both the lowest initial investment

($4,700) and the lowest annual energy savings (5.5 MWh/year), while option 3 has both the highest initial investment ($28,60) and the highest annual energy savings (32.2 MWh/year).

Analysis showed that the reduced infiltration rate retrofit – when installed alone – would not pay for itself over the 20-year period. However, when the reduced infiltration rate retrofit is implemented in conjunction with more efficient cooling equipment, this ECM becomes a viable option. Additionally, as previously demonstrated in section 8.2, the SEER 13 cooling equipment will be able to create more comfortable working atmospheres for the building occupants if the infiltration rates are reduced.

9.2.1 Sensitivity Analysis

A sensitivity analysis on the price of electricity shows that option 1 is the most economically stable investment in terms of the absolute difference in monetary savings. When the electricity cost escalation rate changes from 0% to 9%, the 20-year NPV of option 1 increases from $2,600 to $11,300 and the payback period decreases from 8.8 to 6.5 years, respectively (Figure 9.1 and Figure 9.2). The economics of options 2 and 3 were most sensitive to the future electricity costs, although these options provide significantly higher returns than option 1. The sensitivity analysis showed that the 20-year NPV of options 2 and 3 vary from $10,100 to $55,400 and $17,300 to $66,200, respectively; the payback periods of these options change from 7.8 to 6.0 years and 8.7 to 6.4 years, respectively.

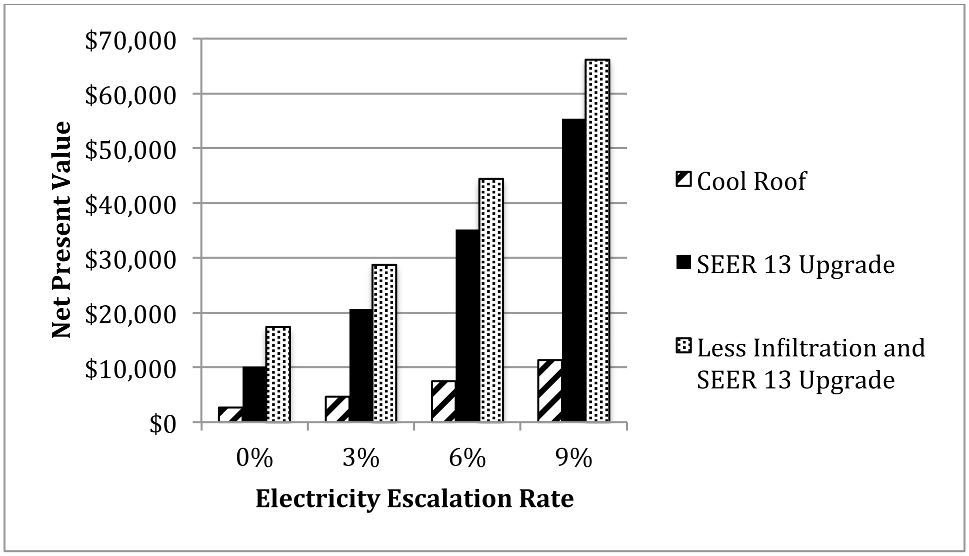


Figure 9.1: Sensitivity of the NPV for the Mechanical Workshop energy conservation measures to changes in the electricity escalation rate

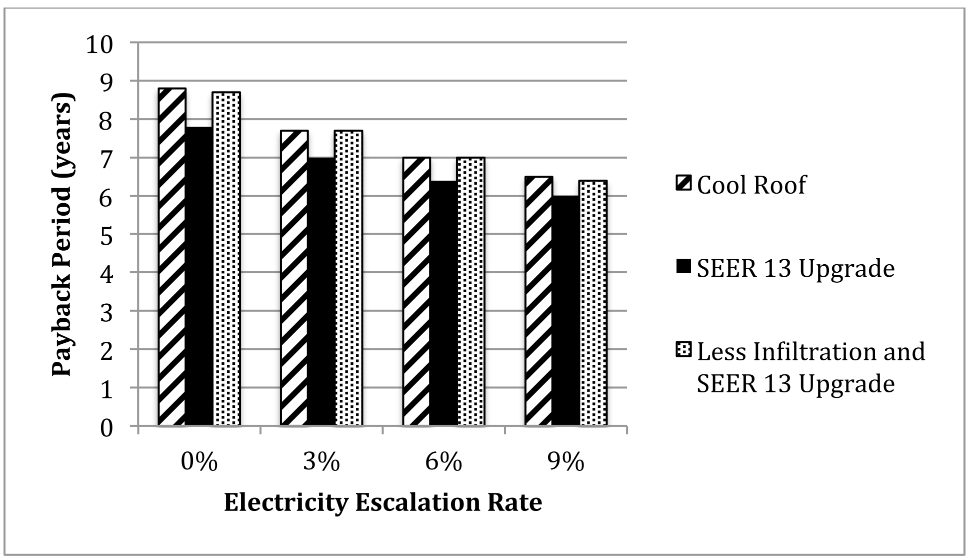


Figure 9.2: Sensitivity of the payback period for the Mechanical Workshop energy conservation measures to changes in the electricity escalation rate

The results show that although options 2 and 3 offer the highest NPVs, the investments may be risky due to the high upfront cost and the dependency on future electricity prices to deliver favorable economic returns. In the worst case scenario (i.e. electricity prices remain constant) options 2 and 3 deliver NPVs of $10,100 and $17,300, which represent 50% and 60% of the initial investment costs, respectively.

9.3 Economic Evaluation of ECMs for the Cisco Building

Analyses for a total of 13 retrofit alternatives were performed for the Cisco Building. Descriptions of the materials, installation costs, and projected savings for each retrofit are given in APPENDIX F. From the analysis, it was found that the only three retrofits that yield positive monetary returns over a 20-year period are the lighting retrofit, the cool roof installation, and the upgrade to SEER 13 cooling equipment. An overview of the economics for these retrofits is shown in Table 9.2. Detailed cash flow analyses for each of these retrofits can be viewed in APPENDIX L.

Table 9.2: Overview of most economically promising retrofits for the Cisco Building

Retrofit and Option No.	Initial Investment	Energy Savings (kWh/yr)	First Year Savings ($)	NPV ($)	Payback (years)	GHG abatement (tCO_2e/yr)
Lighting Retrofit (1)	$3,049	4,370	$656	$4,448	6.5	2.6
Cool Roof (2)	$5,033	3,280	$492	$1,087	17.5	1.9
SEER 13 Upgrade (3)	$30,395	22,390	$3,359	$880	19.0	13.3

Option 2 does not save as much energy as the same retrofit in Mechanical Workshop because the majority of the AC units in the Cisco Building serve the first floor where there is substantial shading from neighboring buildings and vegetation. The economic analysis also showed that reducing infiltration rates by replacing the louvered windows in the Cisco Building will not generate a positive NPV (at any sensitivity rate) and therefore the investment in the retrofit should not be made. However, the lighting retrofit (option 1) showed to be a promising option with the quickest payback period (6.5 years) of the options analyzed for the Cisco Building. An additional easily implemented energy saving solution for the Cisco Building is the removal of phantom loads. A list of specific phantom loads that exist in the Cisco Building can be found in APPENDIX D.

9.3.1 Sensitivity Analysis

Option 1 is the ECM least sensitive to future electricity prices. When the electricity escalation rate changes from 0% to 9%, the payback period of the investment remains considerably stable at 6.0 to 4.9 years and the 20-year NPV varies from $2,800 to $9,700, respectively. Similar to the Mechanical Workshop, the ECM for the Cisco Building that yields the highest energy savings is also the most sensitive to future electricity prices (option 3).

Figure 9.3 shows that options 2 and 3 will not yield positive monetary returns over the next 20 years if electricity prices remain constant. At a 0% electricity escalation rate for a 20-year period, these options will cost UDB $500 and $7,300, respectively. Options 2 and 3 are not shown in the 0% column of Figure 9.4 as the investments will not pay for themselves if the electricity prices do not increase in the future.

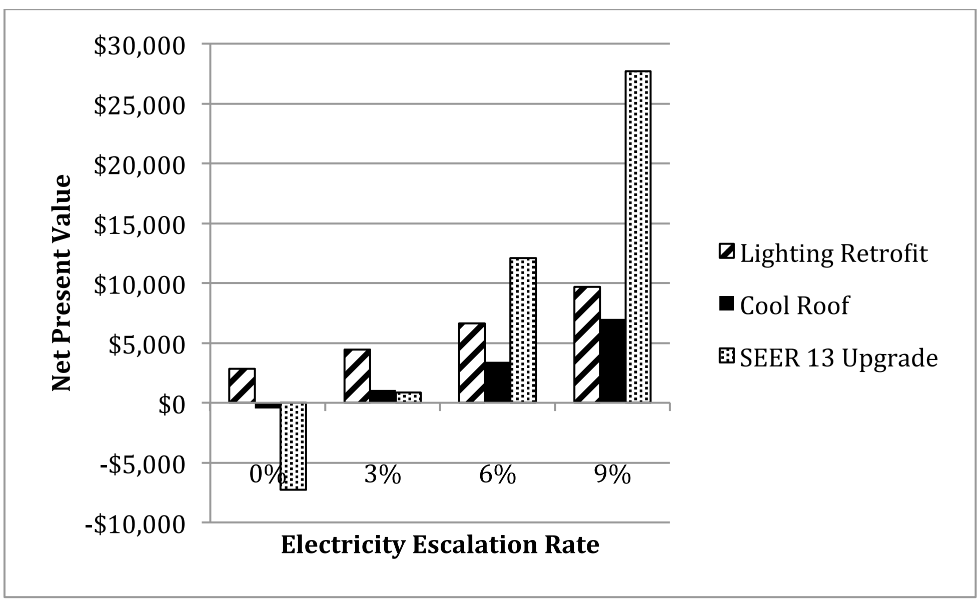


Figure 9.3: Sensitivity of the NPV for the Cisco Building energy conservation measures to changes in the electricity escalation rate

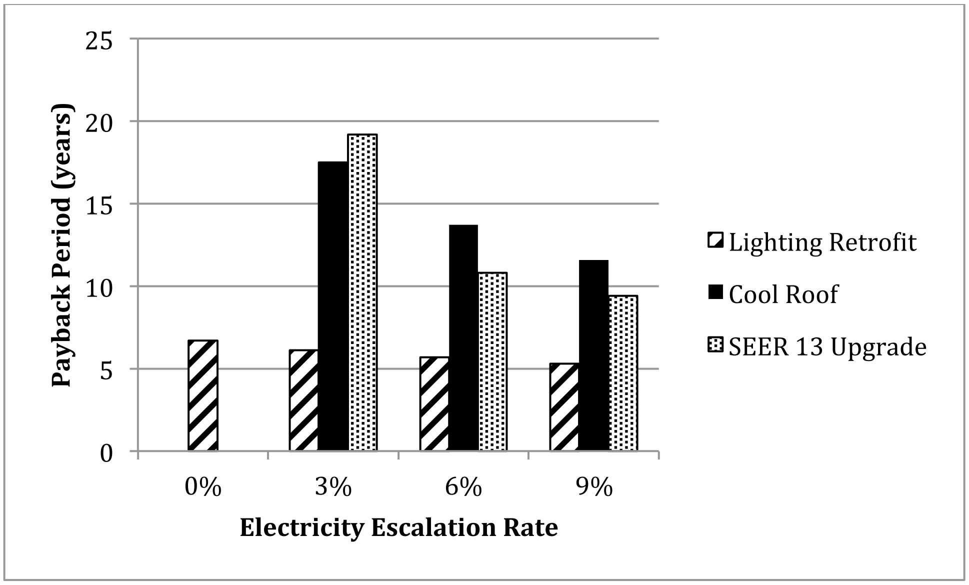


Figure 9.4: Sensitivity of the payback period for the Cisco Building energy conservation measures to the electricity escalation rate

The modest economic fluctuation of option 1 shows that this ECM is a reasonably secure investment. Conversely, options 2 and 3 show high sensitivity; in order for these ECMs to yield positive earnings the price of electricity must increase at a rate of 3% per annum. Because the upfront cost of the SEER 13 upgrade (option 3) is substantively high ($30,400) and yields a comparatively small ($900) NPV, this option can be considered an unsound investment. The upgrade to SEER 13 equipment shows less favorable economics in the Cisco Building than in the Mechanical Workshop simply because the Mechanical Workshop has the greater demand for AC.

9.4 Economic Evaluation of ECMs for the Studio Building

Analyses for a total of 12 retrofit scenarios were performed for the Studio Building. Descriptions of the materials, installation costs, and projected savings for each retrofit are given in APPENDIX G. From the analysis, it was found that the three most favorable retrofits are the reduced infiltration retrofit, less infiltration in conjunction with a cool roof, and the 15-ton chiller with supplemental SEER 13 units. Out of the 12 retrofits, these three had the fastest payback periods; year-by-year economic cash flows for each of the three retrofits can be viewed in APPENDIX M.

Table 9.3: Overview of most economically promising retrofits for the Studio Building

Retrofit and Option No.	Initial Investment	Energy Savings (kWh/yr)	First Year Savings ($)	NPV ($)	Payback (years)	GHG abatement (tCO_2e/yr)
Less Infiltration (1)	$3,452	4,030	$605	$3,954	7.1	2.4
Cool Roof and Less Infiltration (2)	$6,596	5,130	$770	$2,123	13.6	3.0
15-ton Chiller and SEER 13 (3)	$16,600	18,840	$2,826	$12,786	7.3	11.1

Similar to the alternatives for the Mechanical Workshop and Cisco Building, the annual energy savings presented in Table 9.3 are functions of the retrofit's initial investment. Although option 3 has the highest initial investment ($16,600), the retrofit generates the highest NPV ($12,800) with an expected payback of 7.3 years. The Studio Building has fewer windows than the other buildings and therefore reducing the infiltration rates is a less costly investment ($3,500) and provides the fastest payback period (7.1 years) of the options analyzed for the Studio Building.

Similar to the Cisco Building, it is also recommended that phantom loads be removed from the Studio Building. A list of the phantom loads found in the Studio Building is given in APPENDIX D.

9.4.1 Sensitivity Analysis

The analysis shows that reducing infiltration rates in the building (option 1) has the lowest sensitivity to future electricity prices. The addition of a 15-ton chiller and upgrade to SEER 13 (option 3) has the highest economic sensitivity, as it is the retrofit that conserves the most energy (Figure 9.5 and Figure 9.6).

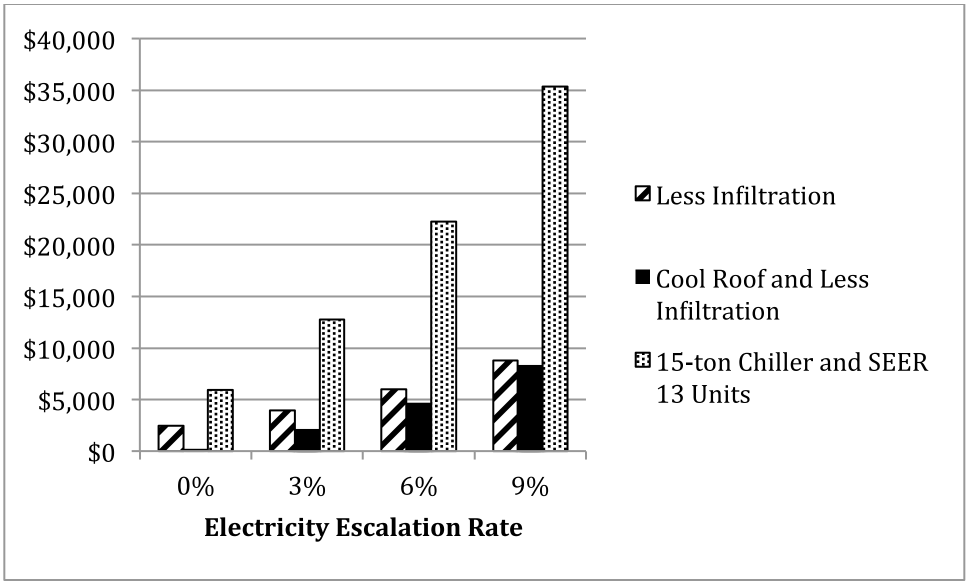


Figure 9.5: Sensitivity of the NPV for the Studio Building energy conservation measures to changes in the electricity escalation rate

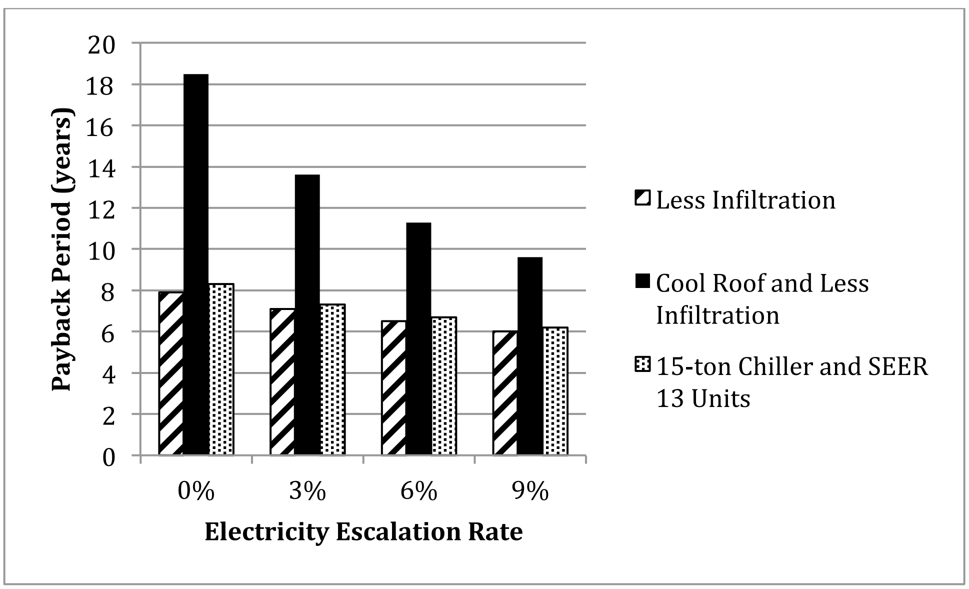


Figure 9.6: Sensitivity of the payback period for the Studio Building energy conservation measures to changes in the electricity escalation rate

As the annual electricity cost escalation rate changes from 0% to 9% for option 1, the 20-year NPV increases from $2,500 to $8,800 and the payback period decreases from 7.9 to 6.0 years, respectively. Option 3 shows another instance where the NPV is highly sensitive to future electricity prices, where higher electricity rates result in considerably higher NPVs. Option 3 also has a relatively stable payback period regardless of the escalation rate and can be considered a secure investment.

9.5 Potential Funding Sources

A barrier to the investment of the aforementioned retrofits and ECMs is likely to be the upfront project costs. Overviews of three possible funding sources are provided in this section.

9.5.1 The U.S. Embassy

Initial funding for UDB's renewable energy research center (CIER) was provided by the U.S. State Department's "Science Corner" program via the U.S. embassy. The funding included the purchase of equipment and books. The U.S. embassy is interested in the long-term success of the CIER and has expressed willingness to help UDB obtain additional funding that will help CIER to expand its collection and activities through at least 2013 (Engel, 2010a). If implemented, the ECMs presented in this report could be used to demonstrate the utility of the CIER; additionally, the measures could be a way of showing students and public the benefits of saving energy. UDB administration should contact the public affairs office at the embassy to pursue this option.

9.5.2 *Alianza en Energía y Ambiente* (AEA)

AEA (Energy and Environment Partnership as translated in English) is an initiative funded by the governments of Austria and Finland that has the objective of promoting renewable energy in Central American countries. This fund occasionally solicits project proposals in renewable energy and energy efficiency; AEA's website can be viewed to check for the latest solicitation.[15] The last open bid for proposals closed on September 17th, 2010.

9.5.3 Establishment of the UDB Energy Independence Fund

To reduce the environmental impacts of campus energy use and resource consumption, many colleges throughout the U.S. have established energy independence funds, where a percentage of student fees are allocated for campus sustainability projects; HSU's Humboldt Energy Independence Fund (HEIF) is one example of such a fund. To fund the ECMs presented in this project, UDB could establish their own energy independence fund. Such a fund could ensure UDB's long-term energy efficiency goals are met while at the same time providing opportunities for active student involvement.

HEIF is funded through the instructionally related activities fee at HSU, which takes $20 per year out of each student's total tuition fees. Currently at HSU, undergraduate tuition is on the order of $7,000 per year, which means that less than 0.3% of student's fees are allocated to HEIF. If UDB were to establish a similar fund, it is recommended that the fees taken out of UDB student tuition to support the fund be on a similar order of magnitude as the fees taken out of HSU student tuition to support HEIF. Ideally, the concept of a UDB Energy Independence Fund would be proposed to UDB students through a general campus vote. Initiating the UDB Energy Independence Fund via a democratic process would insure that students were in favor of their fees being spent on campus energy efficiency projects.

[15] AEA Website: http://www.sica.int/energia/aea/aea_breve.aspx

CHAPTER 10 HSU AND UDB: COMPARISONS IN ENERGY USE

This chapter is intended to strengthen the mutual understanding of energy efficiency issues between the HSU and UDB campuses, and to establish a means by which both HSU and UDB can benefit from their partner university's energy efficiency efforts. The chapter begins with an overview of the unique factors that contribute to disparate trends in energy use between the two campuses. A few key results from selected energy efficiency studies that have been performed on the HSU campus are then presented. These specific results are presented so as to make parallels and contrasts of energy use between the two universities. Finally, specific energy efficiency issues and successes that the two universities have encountered are presented and then compared for transferability.

10.1 University Settings

The different geographical locations of the two universities undoubtedly contribute to disparate trends in energy use. HSU is located in a temperate climate where the energy used to condition buildings is largely driven by the demand for heating. Located in Arcata, CA (latitude 40.9 °N) HSU's necessity for heating is driven by the 5,399 heating degree days (HDD) received each year.[16] Because HSU only experiences five cooling degree days (CDD) per year, air-conditioning (AC) is used sparsely and its use is limited to a few buildings that have large computer labs. Conversely, UDB is situated in the tropical climate of El Salvador (13.4°N) where AC is the sole energy load

[16] HDD figure was retrieved from http://www.degreedays.net, and uses data from 2011-2012.

used to condition buildings. In 2011 UDB experienced approximately 2,100 CDDs and 24 HDDs; no heating equipment is used on the UDB campus.

Another contributing factor to the disparate energy trends between the two universities is the higher proportion of total conditioned buildings at HSU than UDB. At HSU nearly all buildings include a heating and ventilation system, whereas only 11 of the 19 buildings studied at UDB were equipped with cooling systems. The higher percentage of conditioned buildings at HSU makes the campus comparatively more energy intensive than UDB's campus. Additionally, HSU has roughly 90 on and off campus buildings compared to UDB's 19 main campus buildings; the fact that HSU is a larger campus also contributes to HSU's higher energy intensity.

Last, it is useful to note that HSU and UDB consume different forms of energy within campus buildings. To make comparisons of energy use between the two universities possible this chapter normalizes energy use in units of kBtu. Electricity is the sole form of energy delivered to all classrooms and offices on the UDB campus, and propane is only consumed in significant quantities in the cafeteria kitchens. On the other hand, HSU consumes both electricity and natural gas, where the natural gas is primarily used to heat buildings and the electricity is used to power building loads such as lights, mechanical HVAC equipment (i.e. fans, pumps, and blowers), and plug loads such as computers and office machines.

10.2 Trends in Energy use

As mentioned in section 2.5, HEIF is a fund maintained through the fees in HSU student tuition, where the objective of the fund is to alleviate the environmental impact of energy use at HSU. Until the establishment of HEIF in 2007, few efforts had been made to categorize HSU's campus-wide building energy use and only a few of the 90 on and off campus buildings were monitored on an individual building basis. In an effort to correct the lack of individualized building data, HEIF is currently funding student-driven projects and intern positions that will improve building energy data collection and analysis. The more comprehensive data set is intended to support the design and acquisition of a campus-wide building energy management system at HSU. The energy intensities of 20 HSU buildings with available data from 2007 are shown in Figure 10.1.

UDB struggles with a similar problem as HSU in that building energy consumption is currently not monitored on an individual building basis. Figure 10.2 shows the individual BEUI of UDB's buildings using estimates from the strategy developed in Chapter 4. The buildings in Figure 10.2 are listed in order of their overall intensity ranking, which considers both BEU and BEUI. When total energy use at both HSU and UDB is converted into units of kBtu, it is clear that HSU's buildings are more energy intensive. This is mainly attributed to the fact that HSU has a larger proportion of conditioned campus buildings. It is also attributed to fact that there is generally less tolerance in the United States for underconditioned (i.e. unmet heating or cooling demand) buildings. At HSU, building setpoints are generally met no matter what the cost is. Because From Figure 10.1, the most energy intensive buildings on the HSU campus are the Ceramics Lab, the Wildlife Building, and Science D&E Buildings.

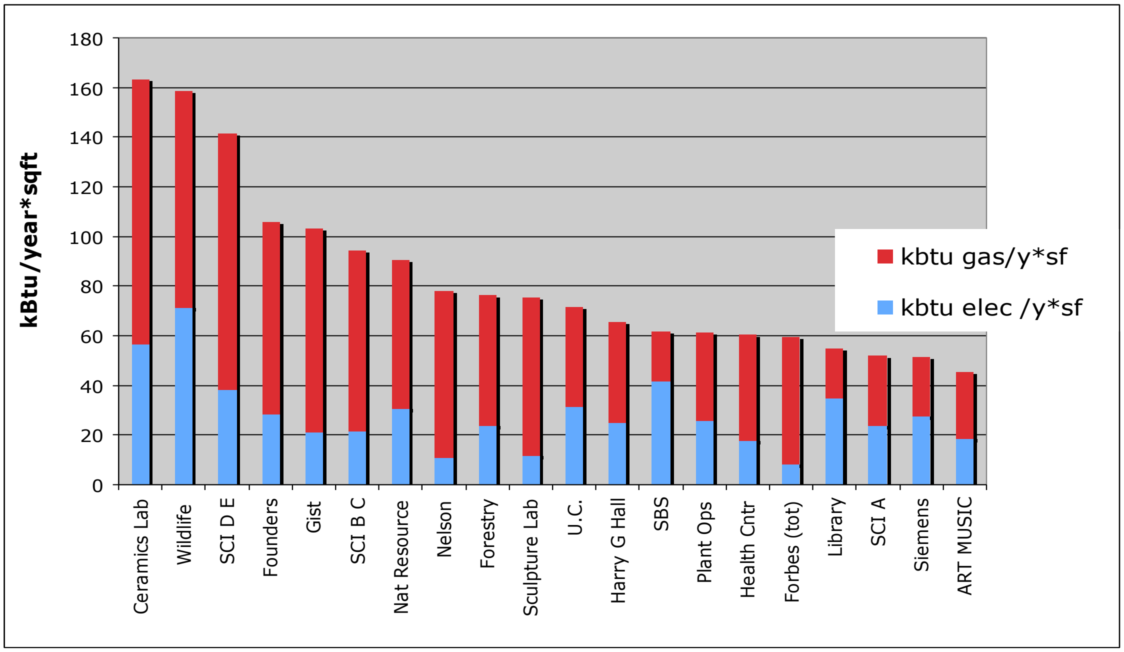


Figure 10.1: HSU campus BEUI for buildings with available data (Credit: Peter Johnstone)

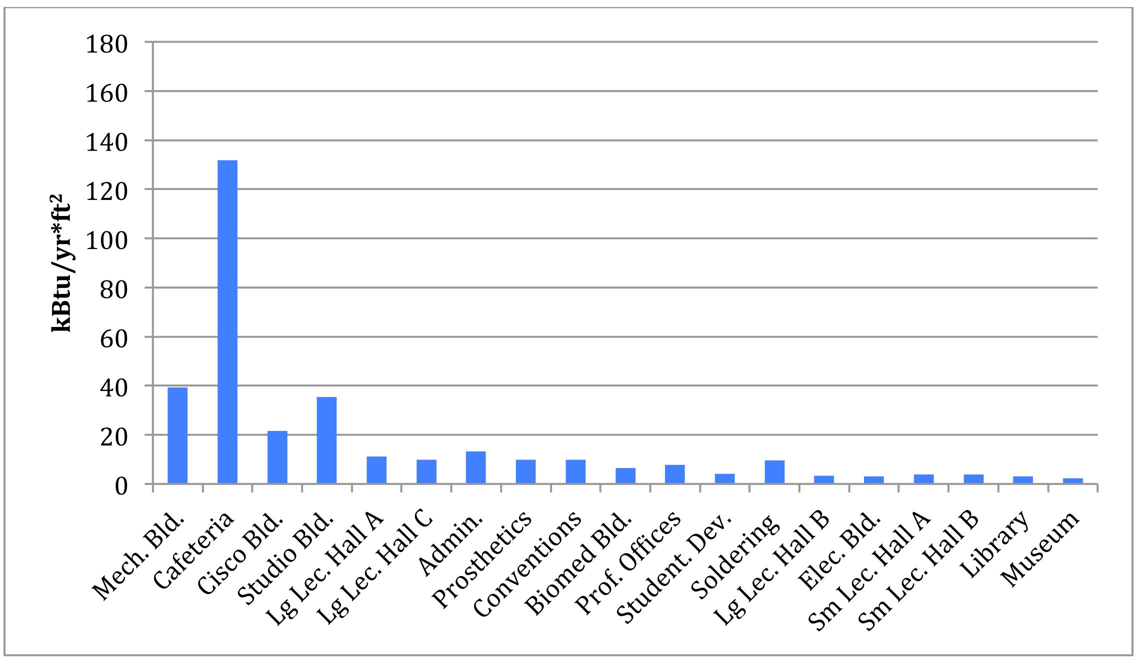


Figure 10.2: UDB campus BEUI for all building on the main campus. All energy data shown were converted from electricity (kWh) to thermal energy (KBtu)

Former HSU graduate student Chhimi Dorji found that the high energy intensity of the Ceramics Lab is due largely to the pot firing kilns and the significant amount of air leakage from the antiquated building envelope combined with heating equipment; the building was constructed in the 1950s as a temporary building and currently uses five unit gas heaters with an average heating input of 85,000 Btu/hr (Dorji, 2010). The high energy intensity of the Wildlife Building was due to large functional equipment demands, which were found to be inelastic and thus ineligible for savings (Johnstone, 2007).

From Figure 10.2, the most energy intensive buildings on the UDB campus are the Mechanical Workshop, Cafeteria, Cisco Building, and Studio Building. With the exception of the Cafeteria, this project has shown that a large reason for the energy loss in those buildings is the inappropriate envelope designs (i.e. roofs and exterior windows). In the case of UDB's hot-humid climate, the poor envelope design contributes to excessive heat gain during the cooling seasons, which is generally all year; in contrast, poor envelope design in HSU's cool-temperate climate results in unwanted heat loss during the heating season.

This project has shown that improvements to the envelope result in as much as a 6.9% decrease in the overall energy (electricity) used for cooling in the Mechanical Workshop; in contrast, the Dorji 2010 study found that envelope improvements to the Ceramics Lab envelope would result in as much as a 12.8% reduction in energy (natural gas) used for heating.

With the exception of upgrades to cooling/heating equipment, both this study and the Dorji 2010 study found that envelope renovations were the most viable retrofits to some of their respective campus's most energy intensive buildings. These cross-climate findings corroborate the aforementioned FSEC claim that mitigating heat transfer across the building envelope is an essential first step in creating energy efficient buildings.

A possible measure of estimating the energy used in a particular UDB building is the total cooling capacity per unit area (Figure 10.3). Excluding the Cafeteria from the data set results in an R-Squared value of 0.42, which can be interpreted as the proportion of the variance in the y-variables attributable to the variance in the x-variables. The value of using this measure at UDB could be to estimate the energy intensity of newly constructed buildings based on the cooling capacity of those buildings. The building occupancy should be taken into account if such an analysis were to be performed at UDB as the buildings below the regression line generally have lower occupancy than the buildings above. To perform a similar analysis of HSU campus buildings would require data on the building's total heating capacity per unit area. No such investigations have been performed at HSU hitherto.

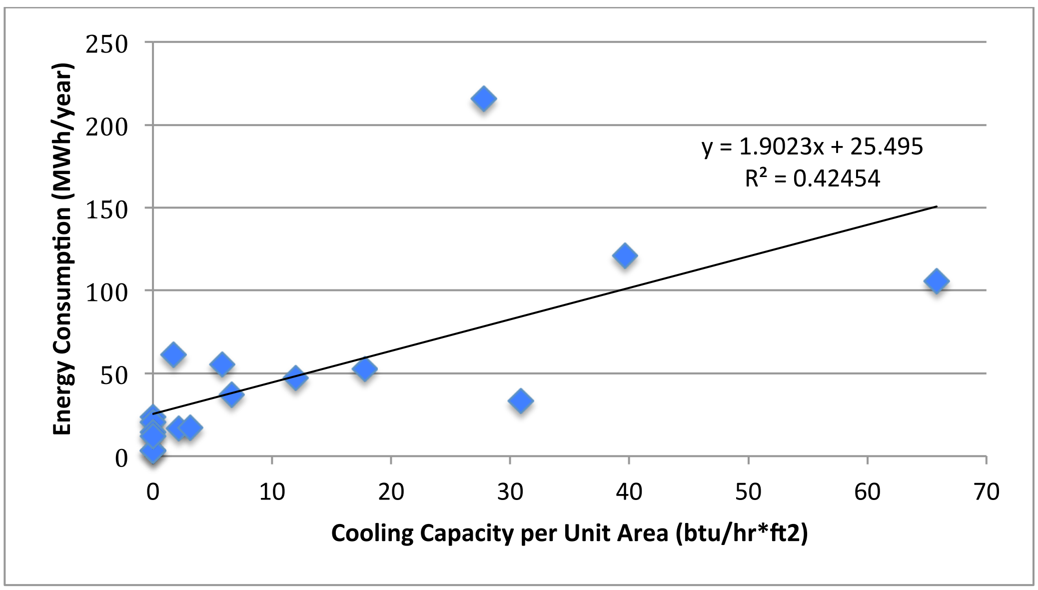


Figure 10.3: Correlation of annual energy consumption v. cooling capacity at UDB

In 2009, as part of a class project a group of HSU graduate students calculated the amount of GHG emissions the HSU campus generates from on campus food consumption and commuting. The study showed that approximately 40 percent of HSU's total GHG emissions come from on campus dining and transportation to and from campus (Tracy et al., 2009). These results show that a significant portion of HSU's environmental impact comes from activities that are not directly tied to building energy use.

Because UDB is almost entirely a commuter school, the university could benefit from a similar study that benchmarks the amount of GHG generated from student transportation and food consumption. If such a study were supplemented by the results presented in this project, UDB would be provided with more comprehensive knowledge of the campus's carbon footprint. Establishing this baseline would be an essential step in monitoring the success of GHG abatement programs, if such programs were pursued.

10.3 Energy Efficiency Projects: Issues and Successes

Many academic programs at HSU provide students with fundamental skills pertaining to environmental sustainability, resource conservation, and ecosystem preservation as core parts of their curricula. Moreover, many of HSU's graduates choose to sign the Graduate Pledge of Social and Environmental Responsibility. Nonetheless, the HSU campus as a whole is still in the nascent stages of mitigating its overall environmental impact.

In 2004, the idea of HEIF was proposed by means of a general HSU student election where roughly 85 percent of the student vote was in favor of the fund. However, because of the struggles with the HSU and California State University (CSU) system administration HEIF was not officially established until 2007 (Comet, 2011). HEIF is currently maintained through additional student fees that fund student driven renewable energy and energy efficiency projects. HEIF has since financed several projects designed by HSU student organizations such as the Renewable Energy Student Union (RESU), Green Campus, and the Campus Center for Appropriate Technology (CCAT).

UDB's energy efficiency developments are in earlier stages than HSU's. UDB's active concern for energy efficiency issues can be traced back to 2009 when the university started El Salvador's first master's degree program in renewable energy management. The program aims to increase El Salvador's technical capacity in the fields of renewable energy and energy efficiency. UDB's renewable energy research center (CIER) was established in 2010 as an additional effort to increase El Salvador's competence in the emerging fields of renewable energy and energy efficiency.

Because roughly 60 percent of HSU's GHG emissions are from building energy use, HEIF's recent projects have focused largely on energy efficiency in buildings. HEIF has had particular difficulty in developing energy efficiency plans for on-campus restaurants and dining service buildings. Reducing energy use in restaurants on the HSU campus is difficult because of the same type of split incentives mentioned in Section 4.3 that create an obstacle for energy efficiency in the UDB Cafeteria.

All of HSU's restaurants and dining halls are operated by one organization, HSU Housing and Dining, which is a fiscally separate entity from the state-owned university. My research shows that HSU currently has only one impactful approach for implementing ECMs in HSU's restaurants and dining halls; this strategy has been initiated through the student organization Green Campus. The approach that Green Campus has taken is to hire interns who perform energy audits of the dining service buildings and provide energy efficiency recommendations at no cost to HSU Housing and Dining (Comet, 2011). Hitherto, Green Campus has been successful in initiating retrofits that include energy efficient lighting and more efficient exhaust fans in the dining hall kitchens. It is possible that the HEIF and Green Campus's approaches could be workable solutions for energy reduction in the UDB Cafeteria.

An issue on both the HSU and UDB campuses is the lack of reliable sub-metered building energy data. HEIF has recently addressed this problem by hiring student interns to focus specifically on campus energy metering projects. These students investigate different energy metering products, energy management systems, and multiple scenarios for implementing higher resolution energy metering on campus. With the work of these students, HEIF hopes to obtain an action plan to better monitor energy use on campus and eventually to implement a single campus-wide energy management system. Work on this HEIF project has not yet been carried out for a period long enough to report any significant progress. However, several past HEIF interns have spent a significant amount of time manually inputting and organizing the existing HSU building energy data from campus meters. This data set has been fundamental for several HSU campus energy efficiency projects. UDB could consider a similar student position to develop an appropriate energy metering plan for UDB's campus and to better organize UDB building energy data. A UDB staff position (i.e. a supervisor or mentor) should also be created to guide this student's efforts.

10.4 Conclusions

In sum, HSU has more buildings that are more widely equipped with conditioning equipment than UDB. In general HSU has higher expectations regarding building comfort and thus the conditioning equipment is utilized in higher capacity and in greater frequency than at UDB. These aspects make HSU's campus comparatively more energy intensive than UDB's. Significant energy losses due to ineffective building envelope designs have been identified at both campuses, which shows that building envelope design is critical to high building performance in both tropical and temperate climates.

Both campuses have had difficulty systematizing building energy data on an individual building basis. HSU has so far made more progress than UDB in consolidating these data through the establishment of HEIF; UDB could consider creating a similar fund to support their respective efforts. Last, split incentives between university and campus dining have been identified at both campuses. HEIF and Green Campus have begun addressing this issue through respective strategies that have moderate success; UDB may consider similar strategies in order to avoid the split incentives found in the UDB Cafeteria.

CHAPTER 11 CONCLUSIONS AND RECOMMENDATIONS

In 2010, the 19 buildings on UDB's main campus consumed approximately 965 MWh of electricity, which resulted in roughly $150,000 (USD) of electricity bills and 571 metric tons of CO_2e emitted into the atmosphere. The key objective of this project was to develop an energy efficiency action plan to reduce energy consumption in the buildings at UDB. This goal was accomplished by identifying three energy intensive buildings on campus, pinpointing the critical energy wastes within those buildings, and developing energy conservation measures (ECMs) with the modeling program eQuest. In this chapter, I summarize the main results of the study, followed by the specific ECMs that I recommend UDB implement in the buildings on campus.

11.1 Conclusions

It was found that UDB's energy consumption records are incomplete and that some buildings do not have individualized sub-meters. It was also found that little work had been done to analyze the data from the existing campus sub-meters. Using the available energy records provided by UDB technicians, a ranking of building energy use (BEU) and building energy use intensity (BEUI) was developed (Table 4.4). This table is intended to serve as a guideline for selection of buildings for future energy efficiency audits.

The most energy intensive buildings on the UDB campus are the Mechanical Workshop, the Cisco Building, and the Cafeteria. However, due to the split incentives between UDB and the restaurant renters in the Cafeteria, the building was not selected for in depth analysis. In place of the Cafeteria, the fourth most intensive building (the Studio Building) was selected for detailed audit and analysis.

The walkthrough audits showed that air conditioning (AC) is the biggest electrical load in all three of the audited buildings. To minimize AC energy consumption, the eQuest modeled retrofits focused on preservation of conditioned air within the building, reduction of radiant heat gain, and installation of more energy efficient equipment. UDB's two most practical design strategies for preserving conditioned air are: (1) the installation of cool roofs and (2) reducing the infiltration rates within conditioned rooms. Through eQuest modeling, it was found that these strategies not only reduce AC energy use, but also provide a cooler, more comfortable atmosphere for building occupants (Figure 8.6 and Figure 8.7).

In all three of the audited buildings, it was found that the most energy is wasted due to the following three causes: (1) intense heat gain from the corrugated metal roofs, (2) excessive infiltration from louvered windows and cracks below doors, (3) and outdated AC equipment. It was also found that the Mechanical Workshop and Cisco Building are optimal buildings to take advantage of lighting retrofits. The most modest energy waste found during the audits was due to the phantom loads in the Cisco and Studio Buildings.

Various retrofit scenarios were modeled in eQuest to assess their energy savings potential and were accompanied by economic analyses. Multiple ECMs were analyzed for each building so as to accommodate whatever budget UDB has available for campus energy efficiency investments. The retrofits can be implemented in steps, starting with the retrofits that have lower initial investments and faster payback periods. With this strategy the savings generated from the cheaper retrofits can be used to facilitate the more expensive ones.

It was found that some retrofit scenarios do not yield a positive return on investment. The replacement of windows in the Cisco Building and the installation of attic fans for the Cisco and Studio building are such examples. In the attic fan scenario, it was found that the AC energy saved is offset by the electric energy consumption of the fan. In the case of the window retrofit for the Cisco Building, it was found that net energy savings are positive but not sufficient to justify the cost to replace the 1,600 ft^2 of louvered windows. However, placing weather stripping below perimeter doors can still be implemented at low cost ($180) to reduce infiltration, although this solution is not as effective as full window replacement.

The economic analysis showed that upgrades to SEER 16 cooling equipment save more energy than SEER 13 and, in most cases, have a higher NPV. However, the upfront cost and time to payback of the SEER 16 retrofits are substantially higher than the SEER 13 retrofits, and as such the SEER 13 retrofits are preferred. Furthermore, there is limited availability of SEER 16 equipment in El Salvador.

The economic evaluation of the 14 retrofit scenarios for the Mechanical Workshop showed that the three best options in increasing order of NPV are: (1) cool roof, (2) an upgrade of all AC units to SEER 13, and (3) a SEER 13 upgrade in conjunction with reduced infiltration rates (Table 9.1). The discounted payback periods of these three retrofits are 7.7 years (1), 7.0 years (2), and 7.7 years (3) respectively. The retrofits have initial investments of $4,700 (1), $24,500 (2), and $28,700 (3) and result in 20-year NPVs of $4,600 (1), $20,700 (2), and $28,700 (3). A complete table of the energy savings potential and economic figures for all 14 retrofit scenarios is given in APPENDIX E.

The analysis of 13 ECMs for the Cisco Building showed that the only three options that yield a positive return over a 20-year period are: (1) the lighting retrofit, (2) the cool roof, and (3) the upgrade to SEER 13 cooling equipment (Table 9.2). The discounted payback periods of these retrofits are 6.1 years (1), 17.5 years (2), and 19.0 years (3). From initial investments of \$3,000 (1), \$4,700 (2), and \$30,400 (3) the NPVs are \$4,800 (1), \$1,100 (2), and \$900 (3). A complete table of the energy savings potential and economic figures for all 13 retrofit scenarios is given in APPENDIX F.

The economic assessment of the 12 ECMs for the Studio Building showed that the three most lucrative options are: (1) reduced infiltration rates, (2) the cool roof in conjunction with reduced infiltration rates, and (3) the central 15-ton AC system with supplemental SEER 13 units (Table 9.3). The discounted payback periods of these three retrofits are 7.1 years (1), 13.6 years (2), and 7.3 years (3), respectively. From initial investments of \$3,500 (1), \$6,600 (2), and \$16,600 (3), the NPVs are \$4,000 (1), \$2,100 (2) and \$12,800 (3). A complete table of the energy savings potential and economic figures for all 12 retrofit scenarios is given in APPENDIX G.

11.2 Recommendations

The following recommendations are the next-step measures that UDB should take to reduce energy consumption on campus:

- UDB should strongly consider measures to establish a system to monitor and log energy use in each of its buildings. Sub-meters should be installed in the buildings listed in Table 4.1 that have a status of “No Meter” or “Grouped”. Such a system is essential for efforts to accurately identify energy savings opportunities and to evaluate progress toward achieving targets.

- Because energy efficiency in any institution is an ongoing project, it is recommended that UDB open a permanent student position or internship to ensure success in meeting campus energy efficiency goals. The responsibilities of this position would include analyzing building energy data and identifying new areas for energy efficiency improvement on campus. This position would also be an ideal way for students to gain real world experience in the field of energy efficiency.
- The expertise that professor Wilfredo Monroy developed while working on this project should be utilized on UDB's campus. It is recommended that professor Monroy give training workshops at the campus renewable energy research center (CIER) for students who are interested in energy efficiency. In these training workshops professor Monroy could explain the tools and the concepts needed to complete an energy audit. The students trained in the course could then be given the opportunity to assist in auditing various campus buildings and developing energy saving solutions.
- Radiant heat gain is a severe issue in the buildings on campus and should be addressed with cool roofs where appropriate. For the Mechanical Workshop and the Studio Building, the cool roof retrofit yields a positive NPV with moderate upfront costs and therefore installation is recommended for these buildings.
- User-operable louvered windows allow a significant amount of outside air to infiltrate conditioned rooms. The windows should be phased out in favor of fixed

windows in the conditioned rooms of the Mechanical Workshop and Studio Building. Further investigations should be made on campus to see where else a window retrofit is appropriate.

- The antiquated AC units in the Mechanical Workshop, Cisco Building, and Studio Building should be upgraded to SEER 13, or higher if possible. In the case of the Studio Building, the duct system should be taken advantage of with a central 15-ton cooling unit. Further feasibility analyses should be conducted on campus to assess the viability of AC upgrades in other buildings. Lastly, SEER 13 or higher should be selected in all cases where a no longer functioning AC unit is replaced.
- The phantom loads in the Cisco and Studio Building should be addressed with power strips. The remainder of the buildings on campus should be investigated for additional phantom loads. This task could be delegated to the student intern position recommended previously. For this approach to be effective it will be critical to accompany any implementation of power strips with an awareness campaign that informs building occupants on the importance of turning off the power strips when the loads are not in use.
- The lighting fixtures in the rooms that are over lit should be replaced with energy efficient diffusors that utilize two T8 tubes instead of four. As with the other retrofits, it is recommended that UDB continue to identify areas where they can reduce the lighting load in campus buildings.
- The UDB administration should collaborate with restaurant managers to develop an energy efficiency plan for the cafeteria.

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LIST OF APPENDICES

APPENDIX A CONVERSIONS FOR BLOWER DOOR DATA

Airflow was recorded at a pressure differential of 50 Pascals (cfm_{50}) during the blower door tests performed in this project. This section describes the techniques used to convert the forced airflow measurement to natural airflow readings according to the LBL infiltration method. Tables for the H, S, and L values are given below as well as explanations of the chosen values; following is a figure for the climate factor C as well as a justification for the final choice.[17]

Table A.1: Building height correction factors

No. of stories	1	1.5	2	3
Correction factor "H"	1.0	0.9	0.8	0.7

Table A.2: Building wind shielding correction factors

Amount of shielding	Well-shielded	Normal	Exposed
Correction factor "S"	1.2	1.0	0.9

Table A.3: Building leakiness correction factors

Type of holes	Small cracks (tight)	Normal	Large holes (loose)
Correction factor "L"	1.4	1.0	0.7

Because infiltration rates were calculated for rooms located on the first and second floor, the correction factor "H" varied between 1.0 and 0.8. UDB's buildings had a fair number of obstructions around their perimeters in the forms of neighboring buildings and vegetation, so 1.0 was used as the correction factor "S" for all cases. Several building fenestrations were found during the walk through audits in the form of louvered windows or crack spaces below perimeter doors; because of these fenestrations a leakiness correction factor "L" of 0.9 was used for all cases.

[17] Correction factor tables and climate factor map were taken from: Meier, Alan. "Infiltration: Just ACH divided by 20?" *Home Energy Magazine* Jan. - Feb. 2004

Because the LBL infiltration model only provides climate factors for the US and Canada it was necessary to estimate the climate factor for El Salvador. The correction factor "C" was estimated based on a comparison of cooling degree day (CDD) data for Key West, Florida and El Salvador International Airport in Comalapa.[18] Key West was initially selected for analysis due to it being the closest latitudinal location with data to El Salvador.

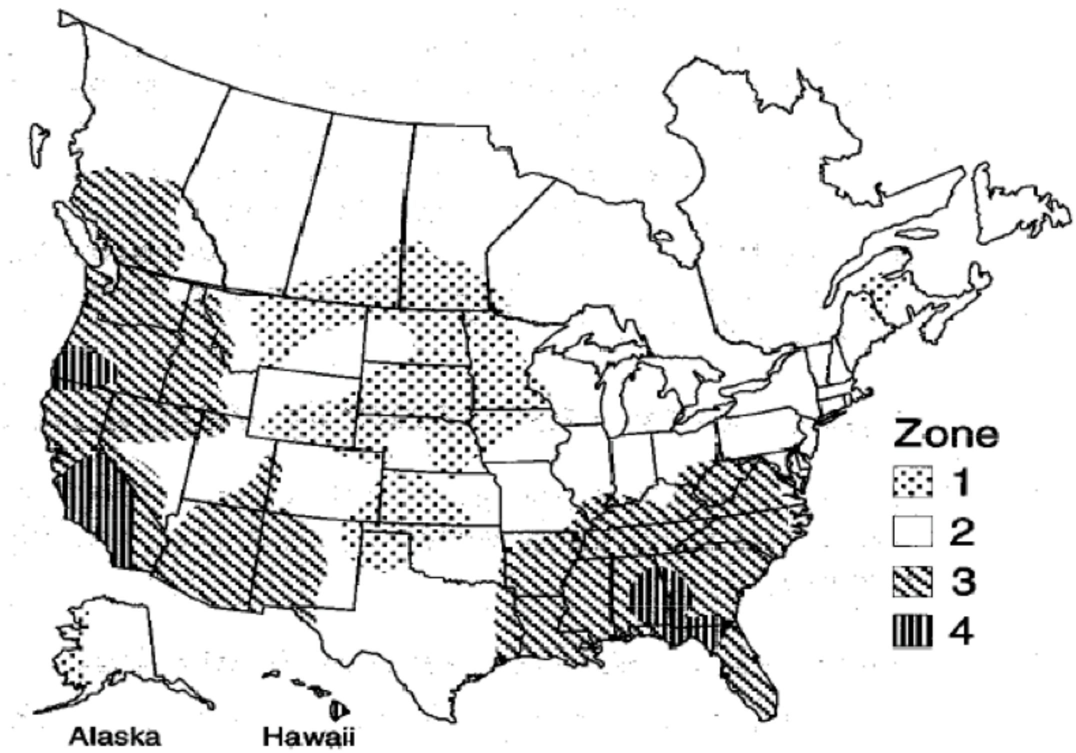


Figure A.1: Map of climate correction factors (only available for US and Canada)

A comparison of CDDs showed that, although the distributions of CDDs over the year were significantly different, annual energy demands for cooling were similar across locations. Southern Florida is located in Zone 3 where the correction factors range from 20-23; a final value of 20 was selected as the correction factor "C" for UDB's buildings.

[18] CDD data were procured from http://www.degreedays.net/

Table A.4: Climate correction factors

Zone	1	2	3	4
Correction factor “C”	14-17	17-20	20-23	23-26

For each zone a range of climate factors is provided. The ultimate climate factor is chosen based upon how close or far away a given site location is from neighboring climate zones. For example, if a project site located in Zone 2 were situated close to the boarder of Zone 1, then 17 would be the ideal climate factor for that site.

Table A.5: Comparison of CDDs for Key West, FL and Comalapa, El Salvador

Month starting	CDD Key West, FL	CDD El Salvador Intl. Airport
12/1/10	3	140
1/1/11	12	174
2/1/11	31	181
3/1/11	68	200
4/1/11	180	198
5/1/11	232	242
6/1/11	298	179
7/1/11	352	179
8/1/11	360	177
9/1/11	315	162
10/1/11	148	113
11/1/11	60	156
Total CDD	**2059**	**2101**

APPENDIX B ESTIMATION OF ADEQUATE ILLUMINANCE LEVELS

The readings from the Extech Q527 were interpreted using the IES method as described in the 1981 IES Lighting Handbook.[19] The IES method provided a procedure for recommending proper illuminance levels to UDB while saving energy on lighting. This section describes the IES method as it applies to the rooms and buildings where illuminance data were recorded. The first step in the IES method is to determine the visual task and plane as described by categories A-I in Table B.1.

Table B.1: Illuminance categories and values for generic indoor activities

Type of Activity	Illuminance Category	Range of Illuminance (Lux)
Public spaces with dark surroundings	A	20-30-50
Simple orientation for short temporary visits	B	50-75-100
Working spaces where visual tasks are occasionally performed	C	100-150-200
Performance of visual tasks of high contrast or large size	D	200-300-500
Performance of visual tasks of medium contrast or small size	E	500-750-1000
Performance of visual tasks of low contrast or very small size	F	1000-1500-2000
Performance of visual tasks of low contrast and very small size over a prolonged period	G	2000-3000-5000
Performance of very prolonged and exacting visual tasks	H	5000-7500-10000
Performance of very special visual tasks of extremely low contrast and small size	I	10000-15000-20000

[19] Kaufman, John E. (1981) "Chapter 2: Lighting System Design Considerations." *IES lighting handbook: application volume 1981-*. New York, N.Y.: The Society. Print.

From the IES lighting handbook design considerations, keyboard reading and computer data processing (computer labs) qualify as illuminance category D; handwritten and printed tasks on size 8 to 10 type font (office work) also qualify as illuminance category D. Each illuminance category provides a range of three possible values (e.g. 200, 300, or 500). The laboratories in the Metrology Department are considered category E. The final illuminance value is selected based on weighting factors as provided in Table B.2.

Table B.2: Weighting factors to be considered when selecting illuminance values

Room and Occupant Characteristics	Weighting Factor		
	-1	0	+1
Occupant ages	Under 40	40-55	Over 55
Importance of speed	Not Important	Important	Critical
Reflectance of task background	More than 70%	30-70%	Less than 30%

After considering all three room and occupant characteristics and adding their corresponding weighting factors, the final illuminance value can be selected. If the total weighting factor is -3 or -2, the smallest illuminance value is chosen; if it is +2 or +3 the highest value is chosen; if it is anything else the middle value is chosen.

For the rooms studied at UDB, the task reflectance backgrounds are considered to be over 70% since the floors are white tile and the walls are painted light colors (weighting factor: -1). The importance of speed is considered important as both students and professors have tasks that must be completed in a timely manner (weighting factor: 0). Lastly, it is not uncommon that occupants over the age of 55 use the facilities (weighting factor: +1). With the sum of these weighting factors, the recommended illuminance level at the task plane for the offices and computer labs in the Mechanical

Workshop and Cisco Building is 300 lux, with the exception of the Metrology labs that have a recommended level of 750 lux.

APPENDIX C SPACE TEMPERATURES

This section presents the space temperature and relative humidity data recorded with the data logger. The data logger was placed inside the attic space (in between the ceiling and roof) of the mentioned buildings for one-week periods. The solid-red lines represent the space temperature (°F) and the dashed-blue lines represent the relative humidity.

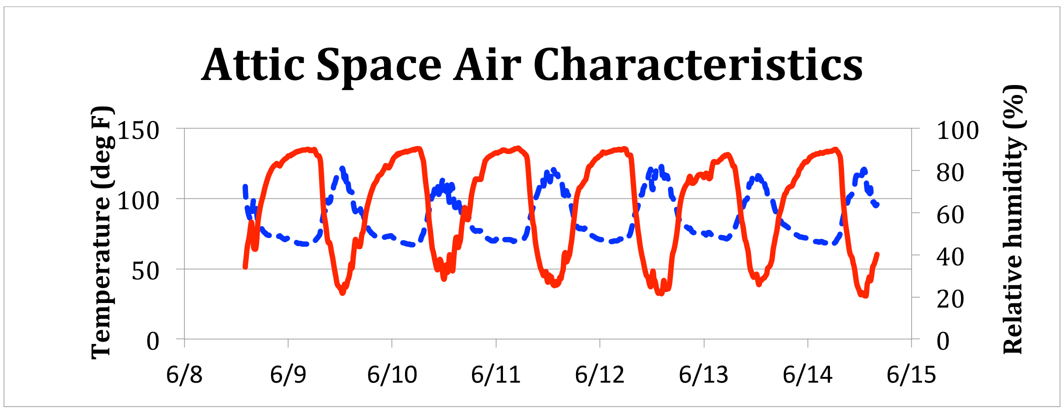


Figure C.1: Temperatures recorded inside the attic of the Studio Building

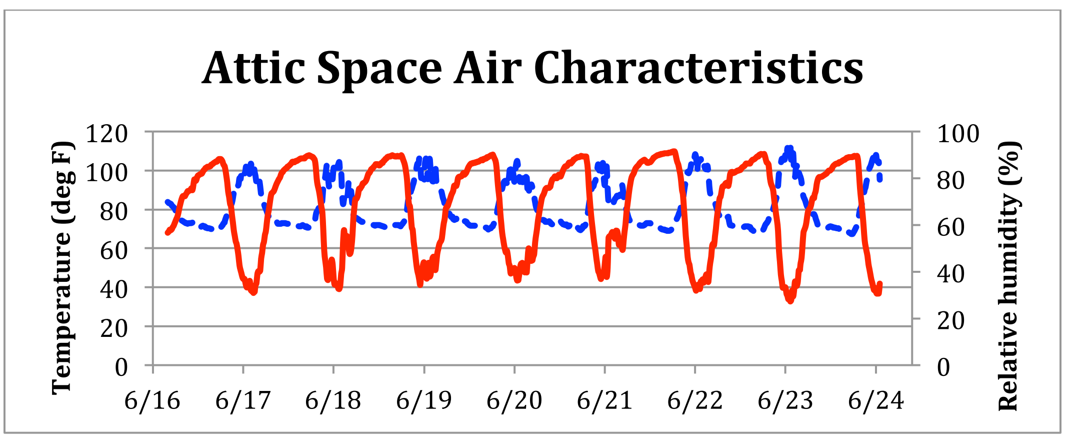


Figure C.2: Temperatures inside the attic of the Mechanical Workshop

In Figure C.1 the peak temperature of the attic is 125 °F for this particular week. The peak attic temperature in Figure C.2 is 113 °F for the respective week.

APPENDIX D LIGHTING RETROFIT AND PHANTOM LOAD REMOVAL

This chapter describes the technicalities of the lighting replacement and phantom load removal. It is assumed that the lighting fixtures in rooms that are over-lit will be replaced with energy efficient diffusors that require only two T8 tubes instead of four. The zones that are over-lit in each audited building are listed in this appendix. The expected illuminance levels that the rooms will receive with the energy efficient diffusors are based on a 20% reduction to the measurements recorded with the light meter. The rooms where phantom loads exist are also identified in this appendix. The rooms and phantom loads are listed to serve as a means for UDB to identify where the loads are so that they can be eliminated. It is assumed that the phantom loads will be removed with a typical 5-outlet power strip. It is important to note that the power strips themselves will not save energy unless the building occupants are educated to turn them off when the loads are not in use. It will therefore be essential to accompany any implementation of power strips with an awareness campaign that teaches building occupants the importance of turning off the power strips when the computers are not in use.

D.1 Mechanical Workshop

A list of zones in the Mechanical Workshop is given in Table D.1. The lighting fixtures in the zones with a status of “over lit” should be replaced for the energy efficient diffusor that require two T8 tubes. No phantom loads were recorded in the Mechanical Workshop; phantom loads may exist, but I was unable to measure them because all outlets in the computer labs were enclosed inside locked cases.

Table D.1: Mechanical Workshop illuminance levels and suggested action

Zone	No. of Fixtures	Status	New Illuminance (Lux)
1st Floor Workshop	48	Over Lit	290
6.21A/B	No Replacement Required		
6.22A/B	No Replacement Required		
6.23	No Replacement Required		
6.24	No Replacement Required		
6.25	No Replacement Required		
6.26	8	Over Lit	284
6.27	No Replacement Required		
Servers	4	Over Lit	293
Help Desks	No Replacement Required		

D.2 Cisco Building

A list of zones in the Cisco Building is given in Table D.2. There is no lighting replacement required in the first floor Metrology labs as the spaces require a higher illuminance level for the researchers.

Table D.2: Cisco Building illuminance levels and suggested action

Zone	No. of Fixtures	Status	New Illuminance (Lux)
5.12	6	Over Lit	308
5.13A	No Replacement Required		
5.13B	No Replacement Required		
5.14A	No Replacement Required		
5.14B	No Replacement Required		
5.15A	No Replacement Required		
5.15B	No Replacement Required		
5.16A	No Replacement Required		
5.17	No Replacement Required		
5.18	8	Over Lit	431
5.2	12	Over Lit	294
5.21	4	Over Lit	308
5.22A	4	Over Lit	396
5.22B	4	Over Lit	317
5.22C	No Replacement Required		
5.24	12	Over Lit	306
5.25	4	Over Lit	308
5.26	4	Over Lit	307
5.27A	6	Over Lit	300
5.27B	6	Over Lit	300
5.28	5	Over Lit	294

A list of the phantom loads that were found in the Cisco Building is given in Table D.3. The phantom loads are limited to the computers and monitors of the Cisco laboratories. In total, these loads represent approximately a 430 W continuous power load.

Table D.3: Cisco Building phantom loads

Room	Equipment	Qty.	Phantom load (W)	Total (W)
5.22A	Computer	15	4	60
5.22A	Monitor	15	4	60
5.22B	Computer	15	4	60
5.22B	Monitor	15	4	60
5.22C	Computer	24	4	96
5.22C	Monitor	24	4	96

D.3 Studio Building

Many of the rooms in the Studio Building are lit with specialty lighting for studio performances or photo shoots. Additionally, the lighting in the offices was found to be at sufficient levels and therefore a lighting retrofit is not recommended for this building.

The phantom loads found in the building are listed in Table D.4. In total the phantom loads constitute roughly a 340 W continuous power load.

Table D.4: Studio Building phantom loads

Room	Equipment	Qty.	Phantom load (W)	Total (W)
2.15	Computer	6	4	24
2.24	Computer	22	4	88
2.24	UPS	2	11	22
2.22	Computer	32	4	128
2.23	UPS	5	16	80

APPENDIX E ESTIMATES FOR MECHANICAL WORKSHOP RETROFITS

This appendix presents the specific materials and installation costs of the retrofits for the Mechanical Workshop (Table E.1). The methodology described in this section applies for the economic analyses for the Cisco Building and Studio Building (Appendix F and Appendix G, respectively).

For each retrofit, the materials costs are the sum of the cost reference numbers as shown in Table E.2 and account for 10 percent sales tax. In the case of the sealed windows (component five) and all Lennox SEER 13 units (components 9-13) tax and installation costs were included in the price quotes. All materials costs were obtained from suppliers within the department of San Salvador with the exception of the reflective insulation for the cool roof and all SEER 16 units, which I was not able to obtain prices for in El Salvador. The reflective insulation includes shipping costs (from its supplier in U.S.) of roughly 50 percent the product's total value. To account for shipping on the SEER 16 equipment the prices shown are double the average unit cost found in the U.S. Installation costs are based on the average wage of UDB technicians; the installation costs account for a team of three UDB technicians working for two to six days, depending on the retrofit.

Table E.1: Economic comparison of retrofit alternatives for the Mechanical Workshop

Alternative Name and Cost Reference Numbers	Upfront Costs ($)			Energy Savings		Economics	
	Materials	Install	Total	kWh/yr	$/yr	NPV ($)	Payback (years)
Cool Roof (2,3)	$4,649	$384	$5,033	5,540	$831	$4,708	7.6
0.5 ACH (4,5)	$4,142	Included in Price Quotes	$4,142	2,070	$310	-$338	N/A
Lighting Retrofit (6,7)	$3,003	$260	$3,263	2,977	$446	$695	16.1
SEER 13 Upgrade (8-12,17)	$24,505	Included in Price Quotes	$24,505	28,950	$4,343	$20,680	7.0
SEER 16 Upgrade (8,13-17)	$69,605	Included in Price Quotes	$69,605	39,230	$5,885	-$19,747	N/A
Cool Roof and 0.5 ACH (2-5)	$8,790	$480	$9,270	7,810	$1,172	-$392	N/A
SEER 13 and Cool Roof (2,3,8-12,17)	$29,154	$384	$29,538	32,920	$4,938	$28,622	7.5
SEER 13 and 0.5 ACH (4,5,8-12, 17)	$28,647	Included in Price Quotes	$28,647	31,230	$4,685	$28,739	7.7
SEER 13, Cool Roof and 0.5 ACH (2-5,8-12,17)	$33,295	$384	$33,679	35,330	$5,300	$6,091	17.1
SEER 16 and Cool Roof (4,5,8,13-17)	$74,254	$384	$74,638	42,640	$6,396	-$20,560	N/A
SEER 16 and 0.5 ACH (4,5,8,13-17)	$73,747	Included in Price Quotes	$73,747	41,590	$6,239	-$19,267	N/A

Table E.2: Materials costs and descriptions for the Mechanical Workshop Building

Ref. #	Component	Description	Size/ Unit	Cost/Rate	No.	Total	Life (Yr)
1	Power Strip	Ecostrip - 1503E, Phantom Load eliminating power strip	Ea.	$35	25	$875	20
2	Attic Fan	Broan Gable Attic Ventilator - Model 35316, 3.9A, 1600 cfm	Ea.	$129	4	$568	10
3	Reflective Paint	Sherman Williams - Thermoaislante (Highly reflective white paint)	Gal.	$23	30	$757	10
4	Reflective Insulation	Prodex – R-15, emissivity 0.03 (Radiant Barrier)	700 ft^2	$220	12	$3,990	20
5	Windows	Sol Aire - Sealed and Tinted 5mm	9'x9'	$475	7	$3,325	20
6	Weather Stripping	Storm Shield - Weather Barrier	10' long	$23	6	$154	10
7	Reflective - Diffuser	Green Tech - two T8 tube fixture	Ea.	$34	65	$2,431	20
8	32W T8 Tubes	Phillips - 32 W T8	Ea.	$4	148	$592	10
9	1 Ton AC Unit	Lennox -12,000 Btu/hr, SEER 16	Ea.	$900	2	$1,800	15
10	3 Ton AC Unit	Lennox - 36,000 Btu/hr, 13 SEER	Ea.	$1,350	2	$2,700	15
11	4 Ton AC Unit	Lennox - 48,000 Btu/hr, 13 SEER	Ea.	$1,800	3	$5,400	15
12	5 ton AC Unit	Lennox - 60,000 Btu/hr, 13 SEER	Ea.	$2,000	5	$10,000	15
13	8 ton AC Unit	Lennox - 96,000 Btu/hr, 13 SEER	Ea.	$4,000	1	$4,000	15
14	3 Ton AC Unit	Ruud - 36,000 Btu/hr, 16 SEER	Ea.	$5,500	2	$12,100	15
15	4 Ton AC Unit	Ruud - 48,000 Btu/hr, 16 SEER	Ea.	$6,400	3	$21,120	15
16	5 ton AC Unit	Ruud - 60,000 Btu/hr, 16 SEER	Ea.	$7,400	5	$40,700	15
17	8 ton AC Unit	Ruud - 96,000 Btu/hr, 16 SEER	Ea.	$10,000	1	$11,000	15
18	Shade Cover	Wood Structure	Ea.	$50	11	$605	10

APPENDIX F ESTIMATES FOR THE CISCO BUILDING RETROFITS

This appendix presents the specific materials and installation costs of the retrofits for the Cisco Building (Table F.1). A detailed analysis methodology for the Mechanical Workshop was presented Appendix E; the same methodology described in Appendix E was also used to complete the economic analysis for the Cisco Building.

Table F.1: Economic comparison of retrofit alternatives for the Cisco Building

Alternative Name and Cost Reference Numbers	Upfront Costs ($)			First Year Energy Savings		Economics	
	Materials	Install	Total	kWh/yr	$/year	NPV ($)	Payback (years)
Phantom Load Removal (1)	$963	$50	$1,013	2515	$377	$3,609	3.0
Attic Fans (2)	$568	$96	$664	-430	-$65	-$11,910	N/A
Cool Roof (3,4)	$4,717	$384	$5,101	3,280	$492	$1,087	17.5
0.5 ACH (5,6)	$13,977	Included in Price Quotes	$13,977	3,340	$501	-$10,966	N/A
Lighting Retrofit (7,8)	$3,049	$264	$3,313	4,370	$656	$4,448	6.1
SEER 13 Upgrade (9-13,18)	$32,195	Included in Price Quotes	$32,195	22,390	$3,359	-$1,488	21.2
SEER 16 Upgrade (9,14-18)	$100,580	Included in Price Quotes	$100,580	39,980	$5,997	-$58,824	N/A
Cool Roof and 0.5 ACH (3-6)	$18,695	$480	$19,175	3,970	$596	-$14,243	N/A

Table F.1 (continued from prior page): Economic comparison of retrofit alternatives for the Cisco Building

Alternative	Materials	Install	Total	kWh/yr	$/year	NPV ($)	Payback (years)
SEER 13 and Cool Roof (3,4,9-13,18)	$36,912	$384	$37,296	22,910	$3,437	-$7,711	N/A
SEER 13 and 0.5 ACH (5,6,9-13, 18)	$46,172	Included in Price Quotes	$46,172	25,340	$3,801	-$9,759	N/A
SEER 13, Cool Roof and 0.5 ACH (3-6,9-13,18)	$50,890	$384	$51,274	25,490	$3,824	-$14,585	N/A
SEER 16 and Cool Roof (5,6,9,14-18)	$105,297	$384	$105,681	40,380	$6,057	-$65,553	N/A
SEER 16 and 0.5 ACH (5,6,9,14-18)	$114,557	Included in Price Quotes	$114,557	42,150	$6,323	-$68,814	N/A
SEER 16, Cool Roof, and 0.5 ACH (3-6,9,14-18)	$119,275	$384	$119,659	42,540	$6,381	-$75,561	N/A

Table F.2: Materials costs and descriptions for the Cisco Building

Ref. #	Component	Description	Size	Unit	Cost /Rate	No	Total	Life (yr)
1	Power Strip	Ecostrip - 1503E, Phantom Load eliminating power strip		Ea.	$35	25	$963	20
2	Attic Fan	Broan Gable Attic Ventilator - Model 35316, 3.9A, 1600 cfm		Ea.	$129	4	$568	10
3	Reflective Paint	Sherman Williams - Thermoaislante (Highly reflective white paint)		Gal.	$23	30	$757	10
4	Reflective Insulation	Prodex - R-15, 0.03 emissivity	700 ft^2		$220	12	$3,960	20
5	Windows	Sol Aire - Sealed and Tinted 5mm	9'x9'		$475	29	$13,775	20
6	Weather Stripping	Storm Shield - Weather Barrier	10' long		$23	8	$202	10
7	Reflective - Diffuser	Green Tech - two T8 tube fixture		Ea.	$34	66	$2,468	20
8	28W T8 Tubes	Phillips - 28 W T8		Ea.	$4	132	$581	10
9	1 Ton AC Unit	Lennox -12,000 Btu/hr, SEER 16		Ea.	$900	2	$1,800	15
10	3 Ton AC Unit	Lennox - 36,000 Btu/hr, 13 SEER		Ea.	$1,350	6	$8,100	15
11	4 Ton AC Unit	Lennox - 48,000 Btu/hr, 13 SEER		Ea.	$1,800	5	$9,000	15
12	5 ton AC Unit	Lennox - 60,000 Btu/hr, 13 SEER		Ea.	$2,000	2	$4,000	15
13	8 ton AC Unit	Lennox - 96,000 Btu/hr, 13 SEER		Ea.	$8,000	1	$8,800	15
14	3 Ton AC Unit	Ruud - 36,000 Btu/hr, 16 SEER		Ea.	$5,500	6	$36,300	15
15	4 Ton AC Unit	Ruud - 48,000 Btu/hr, 16 SEER		Ea.	$6,400	5	$35,200	15
16	5 ton AC Unit	Ruud - 60,000 Btu/hr, 16 SEER		Ea.	$7,400	2	$16,280	15
17	8 ton AC Unit	Ruud - 96,000 Btu/hr, 16 SEER		Ea.	$10,000	1	$11,000	15
18	Shade Cover for AC Units	Wood Structure		Ea.	$50	9	$495	10

APPENDIX G ESTIMATES FOR THE STUDIO BUILDING RETROFITS

This appendix presents the specific materials and installation costs of the retrofits for the Studio Building (Table G.1). A detailed analysis methodology for the Mechanical Workshop was presented Appendix E; the same methodology described in Appendix E was also used to complete the economic analysis for the Studio Building.

Table G.1: Economic comparisons of retrofit alternatives for the Studio Building

Alternative Name and Cost Component Numbers	Cost ($)			Energy Savings		Economics	
	Materials	Install	Total	kWh/yr	$/yr	NPV ($)	Payback (years)
Phantom Load Removal (1)	$578	$30	$608	2,052	$308	$3,163	2.2
Attic Fans (2)	$426	$96	$522	-670	-$100	-$1,994	N/A
Cool Roof (3,4)	$3,145	$384	$3,529	1,100	$165	$208	19.3
0.5 ACH (5,6)	$3,452	Included in Price Quotes	$3,452	4,030	$605	$3,954	7.1
SEER 13 Upgrade (7-11)	$36,100	Included in Price Quotes	$36,100	13,170	$1,976	-$23,280	N/A
Cool Roof and 0.5 ACH (3-6)	$6,596	$384	$6,980	5,130	$770	$2,123	13.6
SEER 13 and 0.5 ACH (5-11)	$39,552	Included in Price Quotes	$39,552	16,660	$2,499	-$20,319	N/A
SEER 13, Cool Roof and 0.5 ACH (3-11)	$42,696	Included in Price Quotes	$42,696	17,510	$2,627	-$22,225	N/A
15-ton Chiller w/ SEER 13 upgrade (7,8,12)	$16,600	Included in Price Quotes	$16,600	18,840	$2,826	$12,786	7.3

Table G.1 (continued from prior page): Economic comparisons of retrofit alternatives for the Studio Building

Alternative	Materials	Install	Total	kWh/yr	$/year	NPV ($)	Payback (years)
15-ton Chiller w/ SEER 13 upgrade and 0.5 ACH (5-8,12)	$20,052	Included in Price Quotes	$20,052	19,450	$2,918	$10,455	8.9
30-ton Chiller (13,14)	$20,320	Included in Price Quotes	$20,320	14,170	$2,126	$1,462	18.2
30-ton Chiller and 0.5 ACH (5,6,13,14)	$23,772	Included in Price Quotes	$23,772	16,350	$2,453	$2,016	17.8

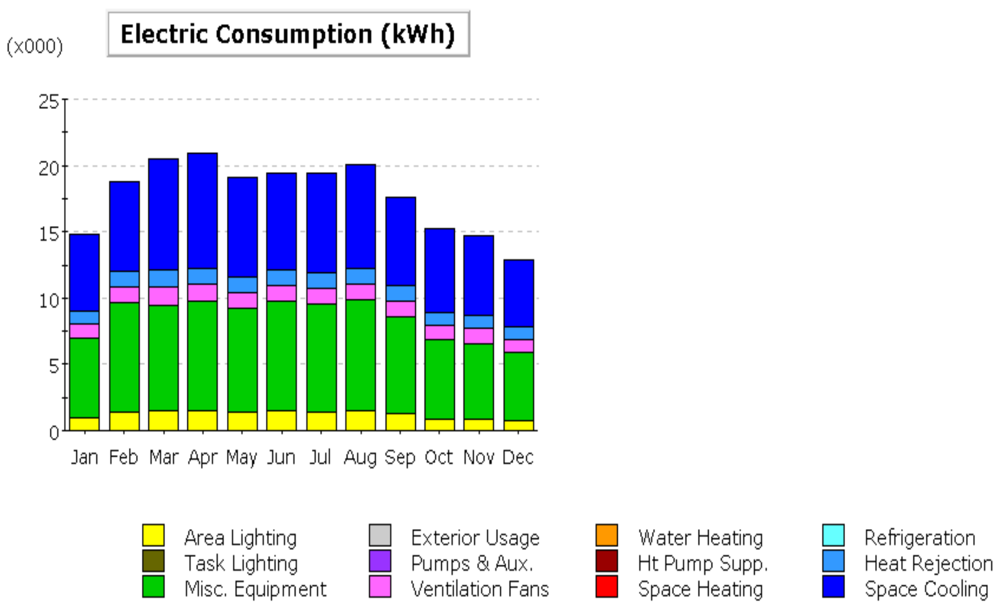
Table G.2: Materials costs and descriptions for Studio Building

Ref. #	Component	Description	Size	Unit	Cost /Rate	No	Total	Life (yr)
1	Power Strip	Ecostrip - 1503E, power strip		Ea.	$35	15	$578	20
2	Attic Fan	Broan Gable Attic Ventilator - Model 35316, 1600 cfm		Ea.	$129	3	$426	10
3	Reflective Paint	Sherman Williams - Thermoaislante (Highly reflective white paint)		Gal.	$23	20	$505	10
4	Reflective Insulation	Prodex - R-15, 0.03 emissivity	700 ft^2		$220	8	$2,640	20
5	Windows	Sol Aire - Sealed and Tinted 5mm		9'x9 '	$475	7	$3,325	20
6	Weather Stripping	Storm Shield - Weather Barrier		10' long	$23	5	$127	10
7	1 Ton AC Unit	Lennox -12,000 Btu/hr, SEER 16		Ea.	$900	3	$2,700	15
8	3 Ton AC Unit	Lennox - 36,000 Btu/hr, 13 SEER		Ea.	$1,350	4	$5,400	15
9	4 Ton AC Unit	Lennox - 48,000 Btu/hr, 13 SEER		Ea.	$1,800	0	$0	15
10	5 ton AC Unit	Lennox - 60,000 Btu/hr, 13 SEER		Ea.	$4,000	3	$12,000	15
11	8 ton AC Unit	Lennox - 96,000 Btu/hr, 13 SEER		Ea.	$8,000	2	$16,000	15
12	15 ton AC Chiller	Lennox - Model TAA180S4D, R-410A, SEER 13		Ea.	$8,500	1	$8,500	15
13	30 ton Chiller	Carrier - Model 30GT-30-600-30 Ton Chiller		Ea.	$13,50 0	1	$13,500	15
14	Added Duct Network	L Connection - Duct Network and Install		ft	$40	15 5	$6,820	20

APPENDIX H MECHANICAL WORKSHOP EQUEST OUTPUT REPORTS

This section provides the simulation results from Mechanical Workshop baseline model, as well as the simulation results of the most promising ECMs for the building.

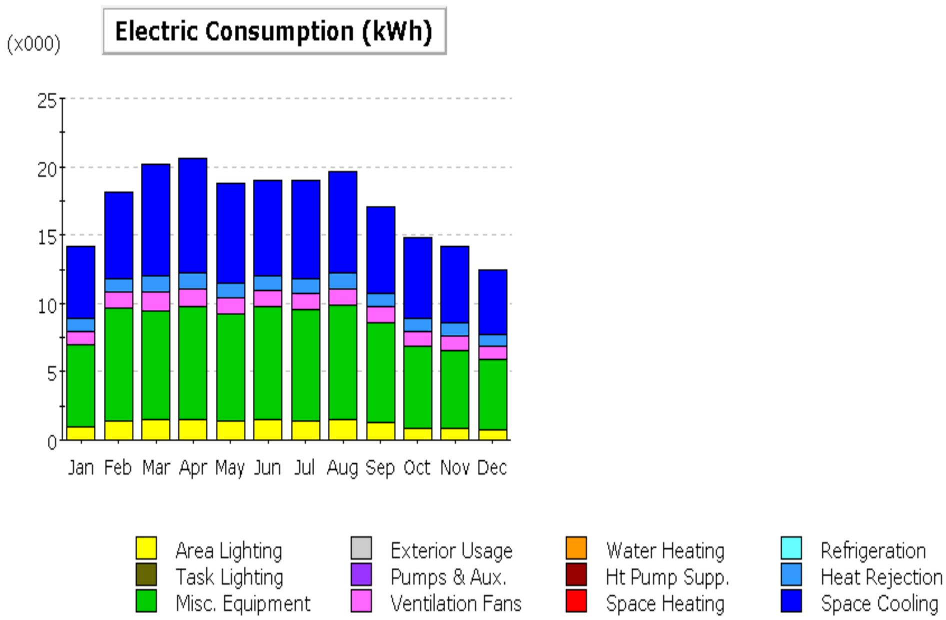
Project/Run: UDB Edificio 6 - baseline 11-7 - Baseline Design Run Date/Time: 03/21/12 @ 23:21



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	5.78	6.80	8.44	8.63	7.53	7.33	7.56	7.79	6.71	6.26	6.02	5.08	83.92
Heat Reject.	0.99	1.11	1.26	1.24	1.11	1.14	1.13	1.18	1.10	1.01	1.03	0.91	13.20
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	1.12	1.23	1.34	1.30	1.17	1.22	1.20	1.25	1.20	1.09	1.13	1.00	14.24
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	5.95	8.19	8.04	8.25	7.87	8.25	8.11	8.35	7.32	5.96	5.72	5.15	87.18
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.97	1.45	1.45	1.48	1.40	1.48	1.44	1.49	1.29	0.90	0.86	0.75	14.94
Total	14.81	18.77	20.53	20.90	19.07	19.42	19.45	20.07	17.62	15.21	14.75	12.89	213.48

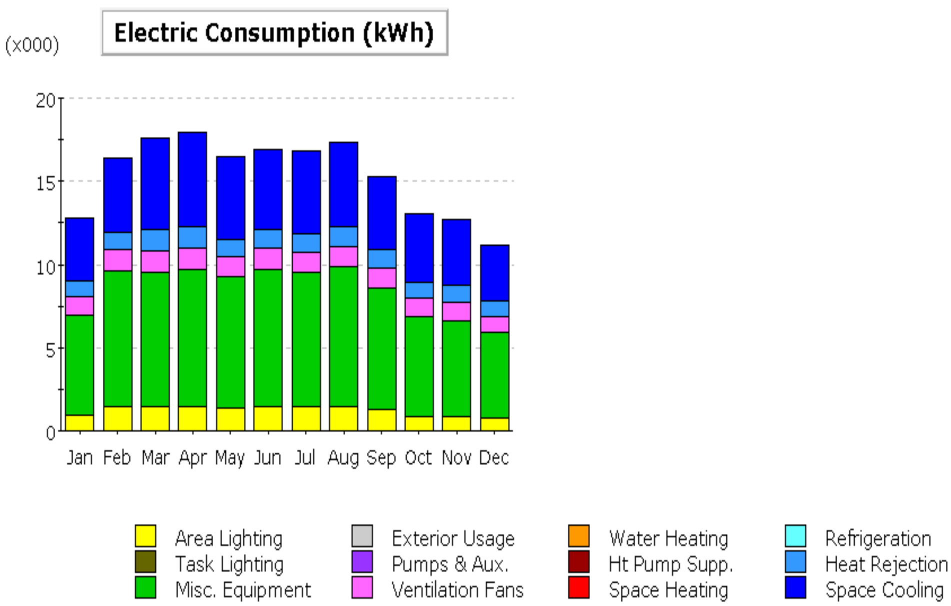
Figure H.1: Mechanical Workshop - Baseline model output



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	5.29	6.29	8.10	8.32	7.26	6.97	7.21	7.42	6.25	5.94	5.59	4.75	79.37
Heat Reject.	0.93	1.05	1.24	1.22	1.08	1.10	1.09	1.14	1.04	0.97	0.97	0.87	12.71
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	1.05	1.16	1.32	1.29	1.15	1.19	1.17	1.22	1.13	1.05	1.05	0.95	13.73
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	5.95	8.19	8.04	8.25	7.87	8.25	8.11	8.35	7.32	5.96	5.72	5.15	87.18
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.97	1.45	1.45	1.48	1.40	1.48	1.44	1.49	1.29	0.90	0.86	0.75	14.94
Total	14.20	18.13	20.15	20.56	18.76	18.98	19.03	19.63	17.03	14.82	14.19	12.46	207.94

Figure H.2: Mechanical Workshop - Cool roof retrofit

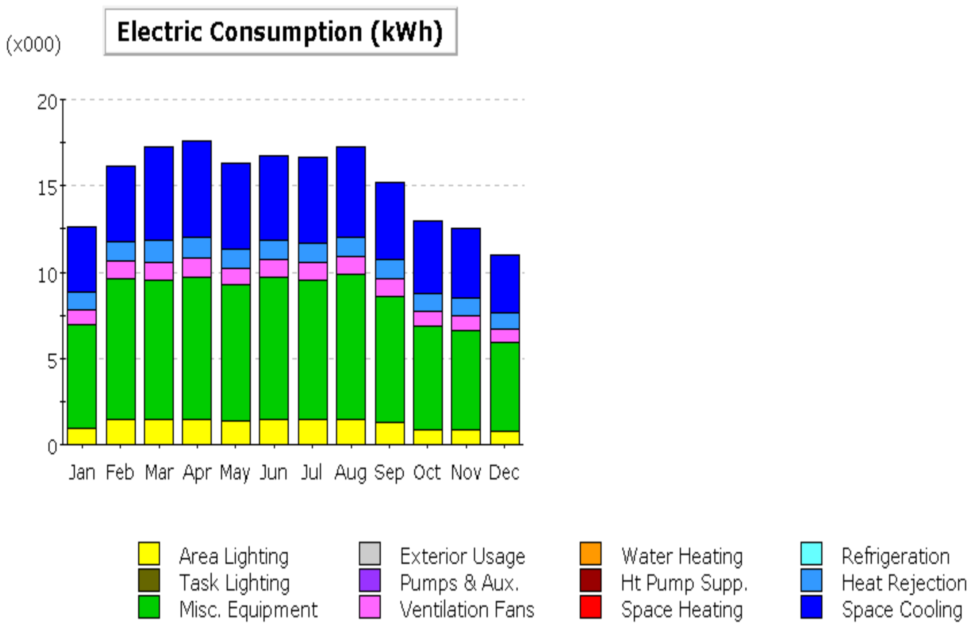


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	3.79	4.45	5.53	5.65	4.93	4.80	4.95	5.10	4.39	4.10	3.94	3.33	54.97
Heat Reject.	0.99	1.11	1.26	1.24	1.11	1.14	1.13	1.18	1.10	1.01	1.03	0.91	13.20
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	1.12	1.23	1.34	1.30	1.17	1.22	1.20	1.25	1.20	1.09	1.13	1.00	14.24
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	5.95	8.19	8.04	8.25	7.87	8.25	8.11	8.35	7.32	5.96	5.72	5.15	87.18
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.97	1.45	1.45	1.48	1.40	1.48	1.44	1.49	1.29	0.90	0.86	0.75	14.94
Total	12.82	16.42	17.62	17.92	16.47	16.89	16.84	17.38	15.31	13.05	12.67	11.14	184.53

Figure H.3: Mechanical Workshop – SEER 13 upgrade

Project/Run: UDB Edificio 6 - SEER 13 and Less ACH - Baseline Run Date/Time: 03/30/12 @ 12:01



Electric Consumption (kWh x000)

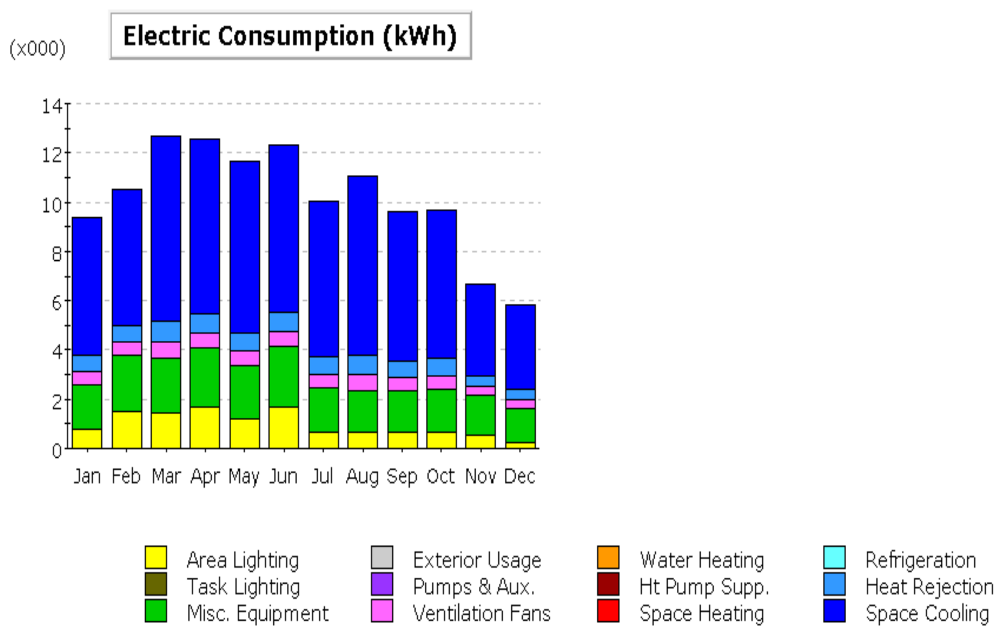
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	3.81	4.42	5.47	5.61	4.95	4.91	5.00	5.18	4.52	4.20	3.98	3.34	55.38
Heat Reject.	0.99	1.09	1.24	1.23	1.10	1.13	1.12	1.17	1.09	1.00	1.01	0.90	13.09
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.92	1.00	1.08	1.06	0.95	1.00	0.97	1.02	0.99	0.90	0.93	0.83	11.66
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	5.95	8.19	8.04	8.25	7.87	8.25	8.11	8.35	7.32	5.96	5.72	5.15	87.18
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.97	1.45	1.45	1.48	1.40	1.48	1.44	1.49	1.29	0.90	0.86	0.75	14.94
Total	12.64	16.15	17.28	17.63	16.27	16.77	16.65	17.22	15.22	12.95	12.50	10.96	182.25

Figure H.4: Mechanical Workshop - SEER 13 and less infiltration retrofit

APPENDIX I CISCO BUILDING EQUEST OUTPUT REPORTS

This section provides the simulation results from Cisco building baseline model, as well as the simulation results of the most promising ECMs for the building.

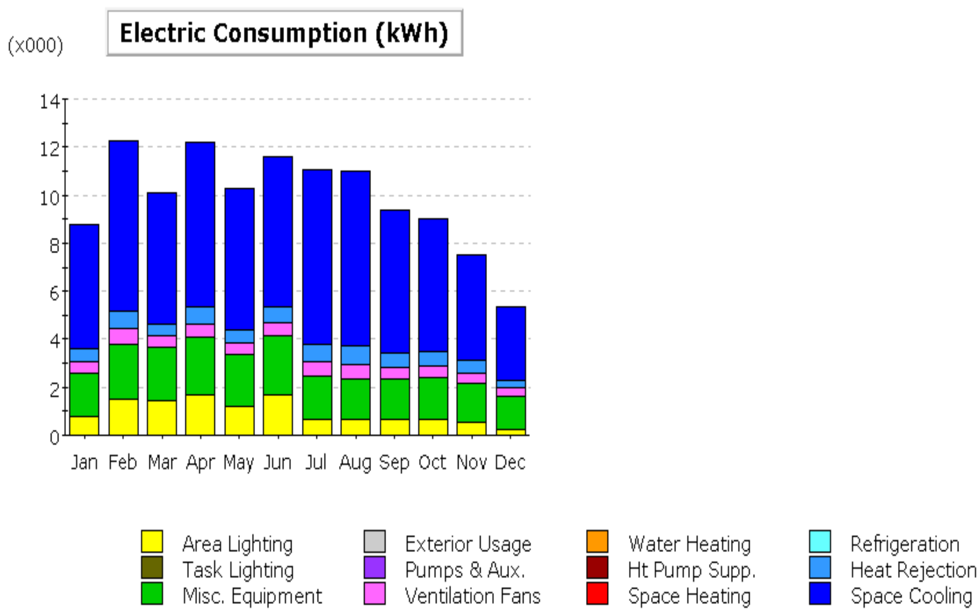
Project/Run: Edificio 5 - baseline - Baseline Design Run Date/Time: 03/22/12 @ 22:20



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	5.55	5.54	7.53	7.08	6.98	6.77	6.32	7.24	6.02	6.02	3.68	3.40	72.12
Heat Reject.	0.69	0.67	0.83	0.77	0.76	0.78	0.70	0.81	0.70	0.70	0.44	0.43	8.28
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.55	0.53	0.66	0.61	0.60	0.62	0.56	0.64	0.56	0.55	0.36	0.35	6.58
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	1.78	2.26	2.23	2.43	2.14	2.44	1.77	1.68	1.66	1.75	1.62	1.40	23.15
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.80	1.52	1.44	1.66	1.20	1.71	0.67	0.68	0.65	0.66	0.55	0.24	11.77
Total	9.36	10.52	12.69	12.54	11.68	12.31	10.01	11.05	9.60	9.67	6.65	5.81	121.90

Figure I.1: Cisco Building – Baseline model output

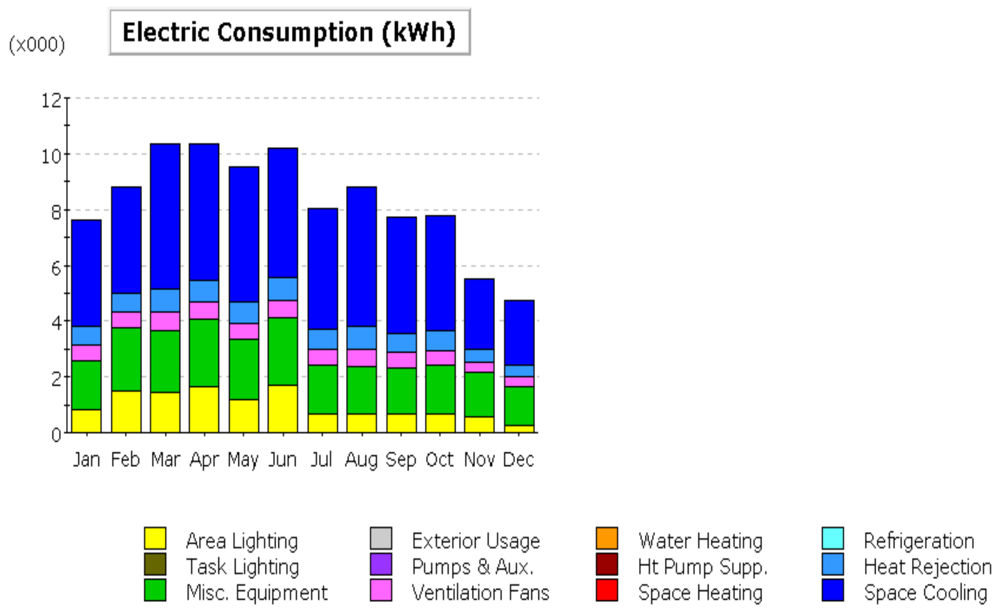


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	5.15	7.06	5.45	6.87	5.88	6.29	7.28	7.28	5.93	5.58	4.44	3.04	70.25
Heat Reject.	0.57	0.77	0.51	0.67	0.58	0.64	0.76	0.75	0.62	0.57	0.50	0.36	7.28
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.49	0.64	0.47	0.57	0.50	0.54	0.60	0.62	0.50	0.49	0.42	0.32	6.15
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	1.78	2.26	2.23	2.43	2.14	2.44	1.77	1.68	1.66	1.75	1.62	1.40	23.15
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.80	1.52	1.44	1.66	1.20	1.71	0.67	0.68	0.65	0.66	0.55	0.24	11.77
Total	8.78	12.25	10.09	12.19	10.29	11.62	11.08	11.00	9.36	9.03	7.54	5.35	118.60

Figure I.2: Cisco Building - Cool roof retrofit

Project/Run: Edificio 5 - SEER 13 - Baseline Design Run Date/Time: 03/22/12 @ 22:39



Electric Consumption (kWh x000)

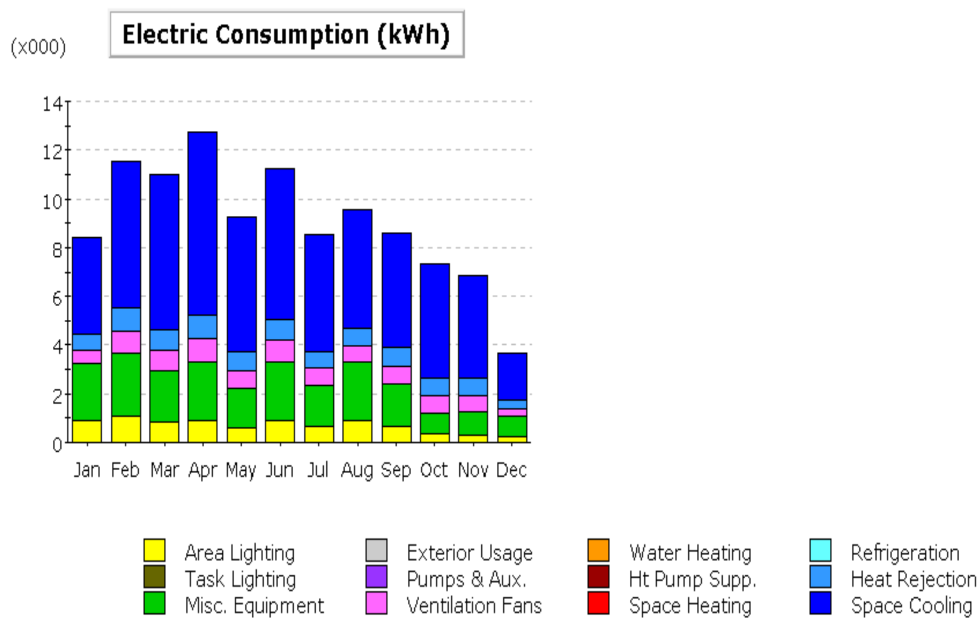
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	3.83	3.82	5.19	4.88	4.81	4.67	4.35	4.99	4.15	4.15	2.54	2.34	49.73
Heat Reject.	0.69	0.67	0.83	0.77	0.76	0.78	0.70	0.81	0.70	0.70	0.44	0.43	8.28
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.55	0.53	0.66	0.61	0.60	0.62	0.56	0.64	0.56	0.55	0.36	0.35	6.58
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	1.78	2.26	2.23	2.43	2.14	2.44	1.77	1.68	1.66	1.75	1.62	1.40	23.15
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.80	1.52	1.44	1.66	1.20	1.71	0.67	0.68	0.65	0.66	0.55	0.24	11.77
Total	7.64	8.80	10.35	10.34	9.51	10.21	8.05	8.80	7.73	7.80	5.51	4.76	99.51

Figure I.3: Cisco Building - SEER 13 upgrade

APPENDIX J STUDIO BUILDING EQUEST OUTPUT REPORTS

This section provides the simulation results from Studio building baseline model, as well as the simulation results of the most promising ECMs for the building.

Project/Run: Edificio 2 Baseline Model 3-7 - Baseline Design Run Date/Time: 12/28/11 @ 10:24

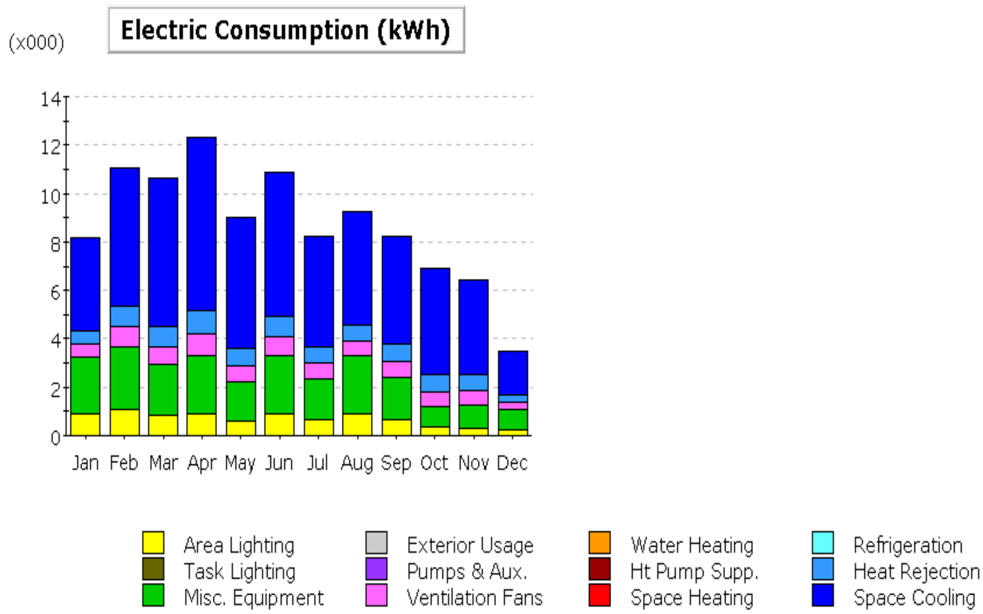


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	4.01	6.03	6.39	7.46	5.58	6.18	4.83	4.86	4.73	4.69	4.21	1.91	60.88
Heat Reject.	0.61	0.93	0.84	0.97	0.74	0.88	0.68	0.68	0.74	0.72	0.68	0.33	8.79
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.59	0.92	0.84	0.97	0.75	0.86	0.68	0.68	0.72	0.71	0.66	0.32	8.71
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	2.31	2.59	2.10	2.41	1.62	2.41	1.73	2.42	1.77	0.81	0.97	0.85	21.98
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.91	1.07	0.82	0.90	0.59	0.90	0.64	0.90	0.66	0.38	0.31	0.24	8.32
Total	8.43	11.53	11.00	12.71	9.28	11.23	8.56	9.53	8.61	7.31	6.84	3.64	108.68

Figure J.1: Studio Building - Baseline model output

Project/Run: Edificio 2 - Less ACH - Baseline Design Run Date/Time: 12/28/11 @ 10:34

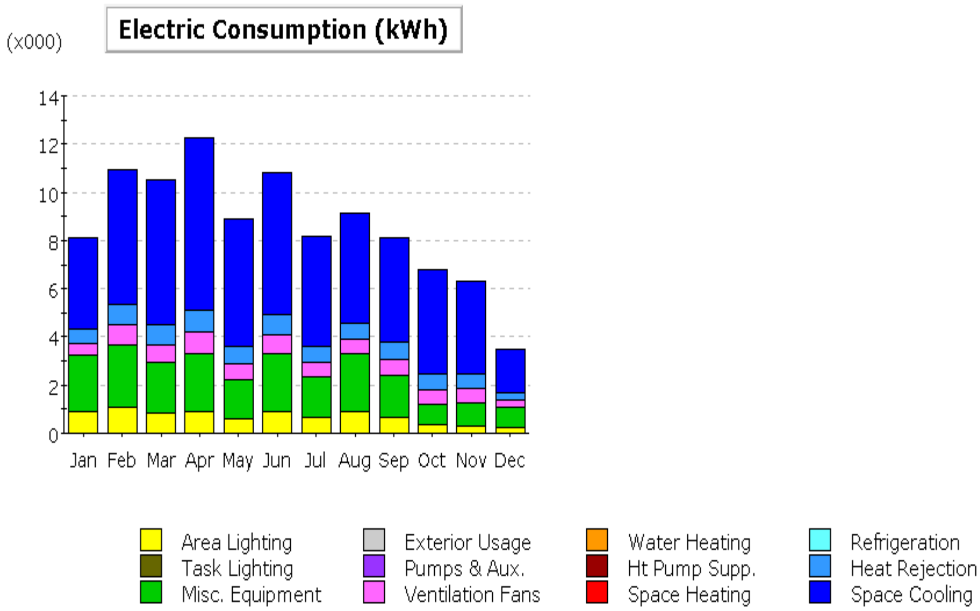


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	3.82	5.71	6.12	7.20	5.38	5.95	4.61	4.66	4.48	4.40	3.90	1.82	58.05
Heat Reject.	0.58	0.88	0.80	0.93	0.72	0.84	0.65	0.65	0.70	0.68	0.63	0.32	8.39
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.54	0.84	0.77	0.89	0.68	0.79	0.62	0.61	0.65	0.64	0.59	0.29	7.91
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	2.31	2.59	2.10	2.41	1.62	2.41	1.73	2.42	1.77	0.81	0.97	0.85	21.98
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.91	1.07	0.82	0.90	0.59	0.90	0.64	0.90	0.66	0.38	0.31	0.24	8.32
Total	8.16	11.08	10.61	12.34	8.99	10.89	8.25	9.24	8.26	6.90	6.41	3.51	104.65

Figure J.2: Studio Building - Less infiltration model output

Project/Run: Edificio 2 - Less ACH and Cool Roof - Baseline DesRun Date/Time: 12/28/11 @ 10:48

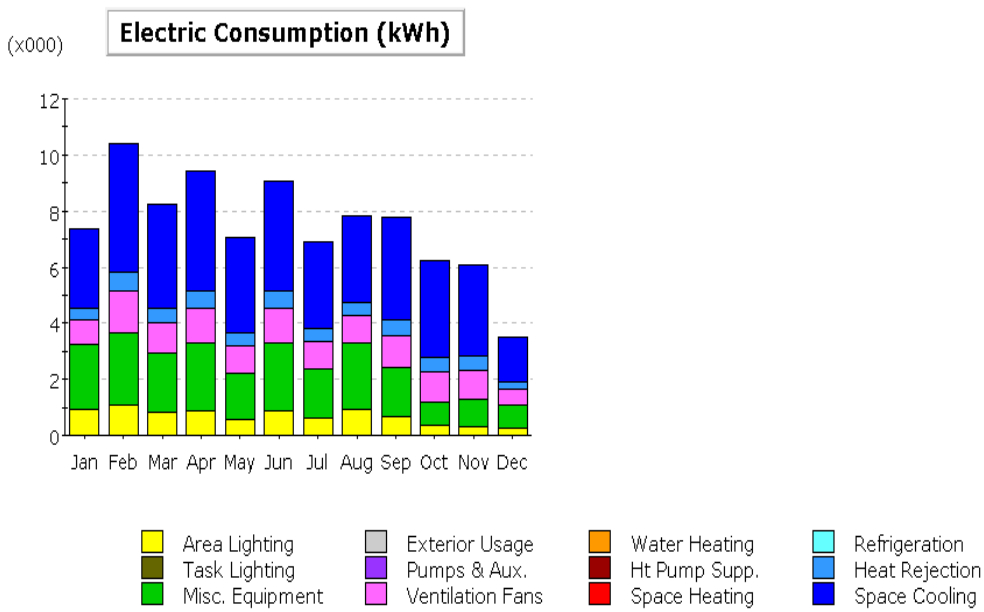


Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	3.76	5.62	6.05	7.13	5.32	5.87	4.54	4.59	4.38	4.29	3.81	1.79	57.17
Heat Reject.	0.58	0.87	0.80	0.93	0.71	0.84	0.64	0.64	0.69	0.66	0.62	0.31	8.29
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.53	0.82	0.76	0.88	0.68	0.78	0.61	0.61	0.64	0.62	0.58	0.28	7.79
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	2.31	2.59	2.10	2.41	1.62	2.41	1.73	2.42	1.77	0.81	0.97	0.85	21.98
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.91	1.07	0.82	0.90	0.59	0.90	0.64	0.90	0.66	0.38	0.31	0.24	8.32
Total	8.09	10.97	10.53	12.25	8.92	10.80	8.16	9.16	8.14	6.76	6.30	3.47	103.55

Figure J.3: Studio Building - Cool roof and less infiltration model output

Project/Run: Edificio 2 - 10 ton chiller, SEER 13 - Baseline Desi(Run Date/Time: 12/28/11 @ 11:00



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	2.79	4.58	3.70	4.24	3.39	3.94	3.11	3.11	3.65	3.43	3.26	1.60	40.79
Heat Reject.	0.44	0.71	0.54	0.62	0.49	0.61	0.47	0.47	0.54	0.51	0.50	0.26	6.15
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.90	1.47	1.08	1.23	0.97	1.22	0.96	0.94	1.13	1.08	1.06	0.55	12.59
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	2.31	2.59	2.10	2.41	1.62	2.41	1.73	2.42	1.77	0.81	0.97	0.85	21.98
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	0.91	1.07	0.82	0.90	0.59	0.90	0.64	0.90	0.66	0.38	0.31	0.24	8.32
Total	7.35	10.41	8.25	9.40	7.06	9.08	6.90	7.83	7.76	6.21	6.10	3.49	89.84

Figure J.4: Studio Building – 15 ton central system with supplemental SEER 13 units retrofit

APPENDIX K MECHANICAL WORKSHOP CASHFLOW ANALYSES

This section contains the 20-year cash flow spreadsheets for the recommended retrofits as recommended in Section 9.2. The results were generated in Microsoft Excel and use an eight percent discount rate and a three percent electricity escalation rate.

Table K.1: Mechanical Workshop - Annual cash flow of cool roof retrofit

Year	Cost (Real Cost)	Benefit (Avoided Costs)	Net Cash Flow	Total Cash Flow	Net Cash Flow @ 8% Discount Rate	Total Cash Flow @ 8% Discount Rate
0	$5,101	$0	($5,101)	($5,101)	($5,101)	($5,101)
1	$0	$831	$831	($4,270)	$769	($4,332)
2	$0	$856	$856	($3,414)	$734	($3,598)
3	$0	$882	$882	($2,533)	$700	($2,898)
4	$0	$908	$908	($1,625)	$667	($2,231)
5	$0	$935	$935	($689)	$637	($1,594)
6	$0	$963	$963	$274	$607	($987)
7	$0	$992	$992	$1,266	$579	($408)
8	$0	$1,022	$1,022	$2,288	$552	$144
9	$0	$1,053	$1,053	$3,341	$527	$671
10	$949	$1,084	$135	$3,476	$62	$733
11	$0	$1,117	$1,117	$4,593	$479	$1,212
12	$0	$1,150	$1,150	$5,743	$457	$1,669
13	$0	$1,185	$1,185	$6,928	$436	$2,105
14	$0	$1,220	$1,220	$8,148	$415	$2,520
15	$0	$1,257	$1,257	$9,405	$396	$2,916
16	$0	$1,295	$1,295	$10,700	$378	$3,294
17	$0	$1,334	$1,334	$12,033	$360	$3,655
18	$0	$1,374	$1,374	$13,407	$344	$3,998
19	$0	$1,415	$1,415	$14,821	$328	$4,326
20	$0	$1,457	$1,457	$16,279	$313	$4,639

NPV Lifecycle cost =	$5,541
NPV Lifecycle benefits =	$10,180
NPV Real Lifecycle Benefits =	$4,639
Simple Payback Period (Years)	5.7
Discounted Payback Period (Years)	7.7

Table K.2: Mechanical Workshop - Annual cash flow of SEER 13 upgrade

Year	Cost (Real Cost)	Benefit (Avoided Costs)	Net Cash Flow	Total Cash Flow	Net Cash Flow @ 8% Discount Rate	Total Cash Flow @ 8% Discount Rate
0	$24,505	$0	($24,505)	($24,505)	($24,505)	($24,505)
1	$0	$4,343	$4,343	($20,163)	$4,021	($20,484)
2	$0	$4,473	$4,473	($15,690)	$3,835	($16,649)
3	$0	$4,607	$4,607	($11,083)	$3,657	($12,992)
4	$0	$4,745	$4,745	($6,338)	$3,488	($9,504)
5	$0	$4,888	$4,888	($1,450)	$3,326	($6,178)
6	$0	$5,034	$5,034	$3,584	$3,172	($3,006)
7	$0	$5,185	$5,185	$8,769	$3,025	$20
8	$0	$5,341	$5,341	$14,110	$2,885	$2,905
9	$0	$5,501	$5,501	$19,611	$2,752	$5,657
10	$616	$5,666	$5,050	$24,661	$2,339	$7,996
11	$0	$5,836	$5,836	$30,497	$2,503	$10,499
12	$0	$6,011	$6,011	$36,508	$2,387	$12,886
13	$0	$6,191	$6,191	$42,699	$2,277	$15,163
14	$0	$6,377	$6,377	$49,076	$2,171	$17,334
15	$24,505	$6,568	($17,937)	$31,140	($5,654)	$11,679
16	$0	$6,765	$6,765	$37,905	$1,975	$13,654
17	$0	$6,968	$6,968	$44,874	$1,883	$15,538
18	$0	$7,177	$7,177	$52,051	$1,796	$17,334
19	$0	$7,393	$7,393	$59,444	$1,713	$19,047
20	$0	$7,615	$7,615	$67,059	$1,634	$20,680

NPV Lifecycle cost =	$32,515
NPV Lifecycle benefits =	$53,196
NPV Real Lifecycle Benefits =	$20,680
Simple Payback Period (Years)	5.3
Discounted Payback Period (Years)	7.0

Table K.3: Mechanical Workshop - Annual cash flow of SEER 13 and less infiltration retrofit

Year	Cost (Real Cost)	Benefit (Avoided Costs)	Net Cash Flow	Total Cash Flow	Net Cash Flow @ 8% Discount Rate	Total Cash Flow @ 8% Discount Rate
0	$28,647	$0	$28,647	$28,647	$28,647	$28,647
1	$0	$4,685	$4,685	$23,962	$4,338	$24,309
2	$0	$4,825	$4,825	$19,137	$4,137	$20,173
3	$0	$4,970	$4,970	$14,167	$3,945	$16,227
4	$0	$5,119	$5,119	$9,049	$3,763	$12,465
5	$0	$5,272	$5,272	$3,776	$3,588	$8,877
6	$0	$5,431	$5,431	$1,654	$3,422	$5,454
7	$0	$5,594	$5,594	$7,248	$3,264	$2,191
8	$0	$5,761	$5,761	$13,009	$3,113	$922
9	$0	$5,934	$5,934	$18,944	$2,969	$3,891
10	$0	$6,112	$6,112	$25,056	$2,831	$6,722
11	$0	$6,296	$6,296	$31,351	$2,700	$9,422
12	$0	$6,484	$6,484	$37,836	$2,575	$11,997
13	$0	$6,679	$6,679	$44,515	$2,456	$14,453
14	$0	$6,879	$6,879	$51,394	$2,342	$16,795
15	$24,505	$7,086	$17,419	$33,975	$5,491	$11,304
16	$0	$7,298	$7,298	$41,273	$2,130	$13,434
17	$0	$7,517	$7,517	$48,790	$2,032	$15,466
18	$0	$7,743	$7,743	$56,533	$1,938	$17,403
19	$0	$7,975	$7,975	$64,508	$1,848	$19,251
20	$0	$8,214	$8,214	$72,722	$1,762	$21,014

NPV Lifecycle cost =	$36,372
NPV Lifecycle benefits =	$57,385
NPV Real Lifecycle Benefits =	$28,739
Simple Payback Period (Years)	5.7
Discounted Payback Period (Years)	7.7

APPENDIX L CISCO BUILDING CASHFLOW ANALYSES

This section contains the 20-year cash flow spreadsheets for the recommended retrofits as recommended in Section 9.3. The results were generated in Microsoft Excel and use an eight percent discount rate and a three percent fuel escalation rate.

Table L.1: Cisco Building - Annual cash flow of lighting retrofit

Year	Cost (Real Cost)	Benefit (Avoided Costs)	Net Cash Flow	Total Cash Flow	Net Cash Flow @ 8% Discount Rate	Total Cash Flow @ 8% Discount Rate
0	$3,313	$0	($3,313)	($3,313)	($3,313)	($3,313)
1	$0	$656	$656	($2,658)	$607	($2,706)
2	$0	$675	$675	($1,982)	$579	($2,127)
3	$0	$695	$695	($1,287)	$552	($1,575)
4	$0	$716	$716	($571)	$527	($1,049)
5	$0	$738	$738	$167	$502	($546)
6	$0	$760	$760	$927	$479	($68)
7	$0	$783	$783	$1,710	$457	$389
8	$0	$806	$806	$2,516	$436	$825
9	$0	$830	$830	$3,347	$415	$1,240
10	$581	$855	$275	$3,621	$127	$1,367
11	$0	$881	$881	$4,502	$378	$1,745
12	$0	$907	$907	$5,410	$360	$2,106
13	$0	$935	$935	$6,344	$344	$2,449
14	$0	$963	$963	$7,307	$328	$2,777
15	$0	$992	$992	$8,299	$313	$3,090
16	$0	$1,021	$1,021	$9,320	$298	$3,388
17	$0	$1,052	$1,052	$10,372	$284	$3,672
18	$0	$1,084	$1,084	$11,456	$271	$3,943
19	$0	$1,116	$1,116	$12,572	$259	$4,202
20	$0	$1,150	$1,150	$13,721	$247	$4,448

NPV Lifecycle cost =	$3,582
NPV Lifecycle benefits =	$8,031
NPV Real Lifecycle Benefits =	$4,448
Simple Payback Period (Years)	4.8
Discounted Payback Period (Years)	6.1

Table L.2: Cisco Building - Annual cash flow of cool roof retrofit

Year	Cost (Real Cost)	Benefit (Avoided Costs)	Net Cash Flow	Total Cash Flow	Net Cash Flow @ 8% Discount Rate	Total Cash Flow @ 8% Discount Rate
0	$5,101	$0	($5,101)	($5,101)	($5,101)	($5,101)
1	$0	$492	$492	($4,609)	$456	($4,646)
2	$0	$507	$507	($4,103)	$434	($4,211)
3	$0	$522	$522	($3,581)	$414	($3,797)
4	$0	$538	$538	($3,043)	$395	($3,402)
5	$0	$554	$554	($2,489)	$377	($3,025)
6	$0	$570	$570	($1,919)	$359	($2,666)
7	$0	$587	$587	($1,331)	$343	($2,323)
8	$0	$605	$605	($726)	$327	($1,996)
9	$0	$623	$623	($103)	$312	($1,684)
10	$949	$642	($307)	($410)	($142)	($1,826)
11	$0	$661	$661	$251	$284	($1,543)
12	$0	$681	$681	$932	$270	($1,272)
13	$0	$701	$701	$1,633	$258	($1,014)
14	$0	$723	$723	$2,356	$246	($768)
15	$0	$744	$744	$3,100	$235	($534)
16	$0	$767	$767	$3,866	$224	($310)
17	$0	$790	$790	$4,656	$213	($97)
18	$0	$813	$813	$5,469	$204	$107
19	$0	$838	$838	$6,307	$194	$301
20	$949	$863	($87)	$6,220	($19)	$282
21	$0	$889	$889	$7,109	$177	$459
22	$0	$915	$915	$8,024	$168	$627
23	$0	$943	$943	$8,967	$161	$788
24	$0	$971	$971	$9,938	$153	$941
25	$0	$1,000	$1,000	$10,938	$146	$1,087

NPV Lifecycle cost =	$5,745
NPV Lifecycle benefits =	$6,027
NPV Real Lifecycle Benefits =	$1,087
Simple Payback Period (Years)	10.6
Discounted Payback Period (Years)	17.5

Table L.3: Cisco Building - Annual cash flow of SEER 13 retrofit

Year	Cost (Real Cost)	Benefit (Avoided Costs)	Net Cash Flow	Total Cash Flow	Net Cash Flow @ 8% Discount Rate	Total Cash Flow @ 8% Discount Rate
0	$30,395	$0	($30,395)	($30,395)	($30,395)	($30,395)
1	$0	$3,359	$3,359	($27,037)	$3,110	($27,285)
2	$0	$3,459	$3,459	($23,577)	$2,966	($24,320)
3	$0	$3,563	$3,563	($20,014)	$2,828	($21,491)
4	$0	$3,670	$3,670	($16,344)	$2,698	($18,794)
5	$0	$3,780	$3,780	($12,564)	$2,573	($16,221)
6	$0	$3,893	$3,893	($8,671)	$2,454	($13,767)
7	$0	$4,010	$4,010	($4,661)	$2,340	($11,428)
8	$0	$4,131	$4,131	($530)	$2,232	($9,196)
9	$0	$4,254	$4,254	$3,724	$2,128	($7,068)
10	$616	$4,382	$3,766	$7,490	$1,744	($5,323)
11	$0	$4,514	$4,514	$12,004	$1,936	($3,387)
12	$0	$4,649	$4,649	$16,653	$1,846	($1,541)
13	$0	$4,788	$4,788	$21,441	$1,761	$219
14	$0	$4,932	$4,932	$26,373	$1,679	$1,899
15	$30,395	$5,080	($25,315)	$1,058	($7,980)	($6,082)
16	$0	$5,232	$5,232	$6,291	$1,527	($4,554)
17	$0	$5,389	$5,389	$11,680	$1,457	($3,098)
18	$0	$5,551	$5,551	$17,231	$1,389	($1,709)
19	$0	$5,718	$5,718	$22,949	$1,325	($384)
20	$0	$5,889	$5,889	$28,838	$1,264	$880

NPV Lifecycle cost =	$40,262
NPV Lifecycle benefits =	$41,142
NPV Real Lifecycle Benefits =	$880
Simple Payback Period (Years)	8.1
Discounted Payback Period (Years)	19.2

APPENDIX M STUDIO BUILDING CASH FLOW ANALYSES

This section contains the 20-year cash flow spreadsheets for the recommended retrofits as recommended in Section 9.4. All analyses use a discount rate of eight percent and an electricity escalation rate of three percent.

Table M.1: Studio Building - Annual cash flow of the less infiltration retrofit

Year	Cost (Real Cost)	Benefit (Avoided Costs)	Net Cash Flow	Total Cash Flow	Net Cash Flow @ 8% Discount Rate	Total Cash Flow @ 8% Discount Rate
0	$3,452	$0	($3,452)	($3,452)	($3,452)	($3,452)
1	$0	$605	$605	($2,847)	$560	($2,892)
2	$0	$623	$623	($2,224)	$534	($2,358)
3	$0	$641	$641	($1,583)	$509	($1,849)
4	$0	$661	$661	($922)	$486	($1,363)
5	$0	$680	$680	($242)	$463	($900)
6	$0	$701	$701	$459	$442	($459)
7	$0	$722	$722	$1,180	$421	($38)
8	$0	$743	$743	$1,924	$402	$364
9	$0	$766	$766	$2,690	$383	$747
10	$0	$789	$789	$3,478	$365	$1,113
11	$0	$812	$812	$4,291	$348	$1,461
12	$0	$837	$837	$5,128	$332	$1,793
13	$0	$862	$862	$5,989	$317	$2,110
14	$0	$888	$888	$6,877	$302	$2,412
15	$0	$914	$914	$7,792	$288	$2,701
16	$0	$942	$942	$8,733	$275	$2,976
17	$0	$970	$970	$9,703	$262	$3,238
18	$0	$999	$999	$10,703	$250	$3,488
19	$0	$1,029	$1,029	$11,732	$238	$3,726
20	$0	$1,060	$1,060	$12,792	$227	$3,954

NPV Lifecycle cost =	$3,452
NPV Lifecycle benefits =	$7,405
NPV Real Lifecycle Benefits =	$3,954
Simple Payback Period (Years)	5.3
Discounted Payback Period (Years)	7.1

Table M.2: Studio Building - Annual cash flow of cool roof and less infiltration retrofits

Year	Cost (Real Cost)	Benefit (Avoided Costs)	Net Cash Flow	Total Cash Flow	Net Cash Flow @ 8% Discount Rate	Total Cash Flow @ 8% Discount Rate
0	$3,452	$0	($3,452)	($3,452)	($3,452)	($3,452)
1	$0	$605	$605	($2,847)	$560	($2,892)
2	$0	$623	$623	($2,224)	$534	($2,358)
3	$0	$641	$641	($1,583)	$509	($1,849)
4	$0	$661	$661	($922)	$486	($1,363)
5	$0	$680	$680	($242)	$463	($900)
6	$0	$701	$701	$459	$442	($459)
7	$0	$722	$722	$1,180	$421	($38)
8	$0	$743	$743	$1,924	$402	$364
9	$0	$766	$766	$2,690	$383	$747
10	$0	$789	$789	$3,478	$365	$1,113
11	$0	$812	$812	$4,291	$348	$1,461
12	$0	$837	$837	$5,128	$332	$1,793
13	$0	$862	$862	$5,989	$317	$2,110
14	$0	$888	$888	$6,877	$302	$2,412
15	$0	$914	$914	$7,792	$288	$2,701
16	$0	$942	$942	$8,733	$275	$2,976
17	$0	$970	$970	$9,703	$262	$3,238
18	$0	$999	$999	$10,703	$250	$3,488
19	$0	$1,029	$1,029	$11,732	$238	$3,726
20	$0	$1,060	$1,060	$12,792	$227	$3,954

NPV Lifecycle cost =	$3,452
NPV Lifecycle benefits =	$7,405
NPV Real Lifecycle Benefits =	$3,954
Simple Payback Period (Years)	5.3
Discounted Payback Period (Years)	7.1

Table M.3: Studio Building – Annual cash flow of 15-ton chiller with supplemental 13 SEER units retrofit

Year	Cost (Real Cost)	Benefit (Avoided Costs)	Net Cash Flow	Total Cash Flow	Net Cash Flow @ 8% Discount Rate	Total Cash Flow @ 8% Discount Rate
0	$16,600	$0	($16,600)	($16,600)	($16,600)	($16,600)
1	$0	$2,826	$2,826	($13,774)	$2,617	($13,983)
2	$0	$2,911	$2,911	($10,863)	$2,496	($11,488)
3	$0	$2,998	$2,998	($7,865)	$2,380	($9,108)
4	$0	$3,088	$3,088	($4,777)	$2,270	($6,838)
5	$0	$3,181	$3,181	($1,596)	$2,165	($4,673)
6	$0	$3,276	$3,276	$1,680	$2,065	($2,609)
7	$0	$3,374	$3,374	$5,054	$1,969	($640)
8	$0	$3,476	$3,476	$8,530	$1,878	$1,238
9	$0	$3,580	$3,580	$12,110	$1,791	$3,029
10	$0	$3,687	$3,687	$15,797	$1,708	$4,737
11	$0	$3,798	$3,798	$19,595	$1,629	$6,366
12	$0	$3,912	$3,912	$23,507	$1,553	$7,919
13	$0	$4,029	$4,029	$27,536	$1,482	$9,401
14	$0	$4,150	$4,150	$31,686	$1,413	$10,813
15	$16,600	$4,275	($12,325)	$19,361	($3,885)	$6,928
16	$0	$4,403	$4,403	$23,763	$1,285	$8,213
17	$0	$4,535	$4,535	$28,298	$1,226	$9,439
18	$0	$4,671	$4,671	$32,969	$1,169	$10,608
19	$0	$4,811	$4,811	$37,780	$1,115	$11,722
20	$0	$4,955	$4,955	$42,736	$1,063	$12,786

NPV Lifecycle cost =	$21,833
NPV Lifecycle benefits =	$34,619
NPV Real Lifecycle Benefits =	$12,786
Simple Payback Period (Years)	5.5
Discounted Payback Period (Years)	7.3